Weather Information for Surface Transportation

A White Paper on
Needs, Issues and Actions

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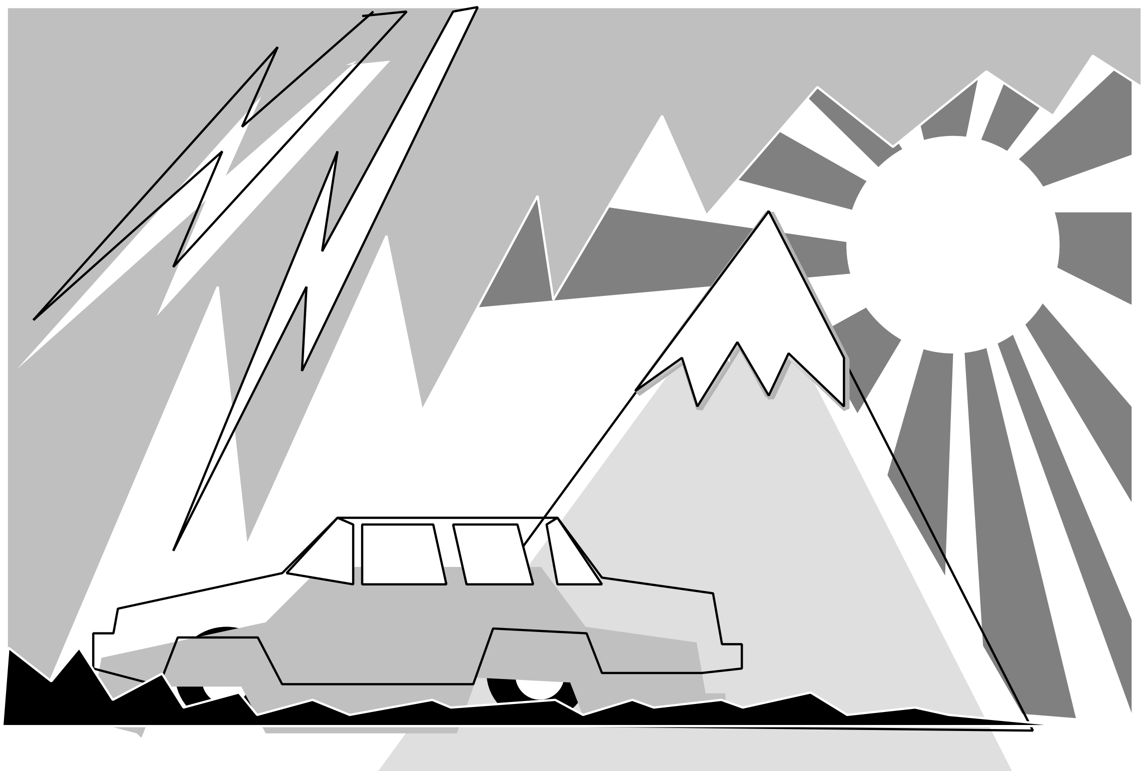

by:

The Weather Team

Office of Safety and Traffic Operations
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U.S. Department of Transportation

Weather Information for Surface Transportation

The Weather Team

The Weather Team is a cross-agency group, initiated by the rural Intelligent Transportation System (ITS) program of the United States Department of Transportation. For further information, or to make comments on this paper, contact:

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The Weather Team is coordinating federal ITS requirements and programs for weather information that serves surface transportation decision makers. This White Paper has made use of valuable contributions by a number of people in the transportation and meteorological communities. This White Paper analyzes needs for, and issues concerning, federal coordination of activities that will contribute to better weather-related transportation system outcomes by providing better decision support to transportation operators and users.

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Executive Summary

Introduction and Purpose

The Federal Highway Administration (FHWA) Weather Team was formed in 1997 under the Intelligent Transportation System (ITS) program of the U.S. Department of Transportation (USDOT). The team currently has FHWA members and a state DOT representative, but considers weather information needs of all surface transportation modes. The team is coordinating with the National Weather Service (NWS) of the Department of Commerce as the primary provider of weather information. The team intends to include all USDOT surface modal administrations and will coordinate with the well-established weather interests of the aviation and maritime administrations.

This White Paper focuses on the needs of surface transportation decisions for better support by weather information, integrated with other information in the ITS. Findings are included from a special team workshop and feedback from conference presentations, representing wide participation by transportation and meteorological experts, in the public and private sectors. The goals of the ITS program and of the FHWA National Strategic Plan are to be met by a conceptual Weather Information for Surface Transportation (WIST) System that will be part of the ITS for use by surface transportation operators and travelers.

The FHWA role is to promote deployment of the WIST System by local transportation agencies with private partners, through the framework of the National ITS Architecture. Research projects and operational tests are planned, and one test is already underway, under the rural ITS program budget. The team hopes to focus a variety of USDOT and other funding sources through a surface transportation weather plan.

Transportation Outcomes and Weather Information

The goal of the WIST System is to achieve better outcomes in the surface transportation system, and weather information is a *resource* to decision making that can achieve this goal. Weather itself is a natural constraint on transportation, but weather information as part of better decision support can improve treatment of weather effects on surface transportation facilities, allow travelers to cope better with conditions, and expedite responses to weather-induced problems.

The market for improved decision support using weather information is the operation of the extensive network of highways, rail and inland waterway, and all the trips on that network. This market stratifies by type of trip and network component. There are nearly four million miles of public roads in the U.S., but half of all vehicle miles are carried on just 5% of this--the Interstates and major arterials that include 130,000 miles in rural areas. This high-intensity network can be covered effectively by sensors and information media that will serve most long trips. The problem is how to serve efficiently the remaining 95% of mileage, and roughly the same percentage of land area, in the rural U.S.

The goal is to improve outcomes affected by weather: safety, travel time, throughput, user satisfaction, environmental impacts and costs in the surface transportation system. The most is known about treatment costs. About $2.1 billion per year are spent on snow removal and ice treatment, and Road Weather Information Systems (RWIS) are already paying their way by making road maintenance more efficient while reducing environmental impacts of salt use. About 20% of fatal and injury crashes occur in adverse weather conditions, but it is difficult to analyze weather as a causal factor, or the role of better information. Using information for safer travel behavior, and avoiding unsafe conditions, is an issue of human factors and the delivery of credible advisories when and where they are needed. In dollar value, it is likely that the single biggest impact of weather is on delay and congestion costs. The data and analyses to separate weather from other congestion effects, and to estimate potential benefits from information, are almost wholly lacking. Effectiveness in reducing weather-related delay requires coordination of treatment, traffic management and traveler information.

Better evaluation of outcomes for development of the WIST System, and adaptive learning in its operation, has to be built into the ITS. Pending that, it is reasonable to believe that small investments in better decision support with *existing* weather and transportation information can have large benefits in safety, travel time and costs. Better weather information sources will require more transportation agency investment in specialized sensors, and will be produced through continued NWS modernization. In these cases the issues are determination of optimal investment levels, and coordination with the NWS on specific surface transportation needs.

A WIST System Vision

The primary vision for the WIST System is:

> *Transportation system operators and users have readily-available weather information that is accurate, reliable, appropriate and sufficient for their needs. The resulting decisions effectively improve the safety, efficiency and customer-satisfaction of the transportation system.*

This vision will be realized within the ITS by an open system that maximizes the sharing of information. Structurally, the WIST System has a common information infrastructure that supports user-specific applications. The infrastructure consists of openly shared databases for weather and transportation. The weather information will continue to be supplied publicly by the NWS, and will be augmented by the specialized observations on transportation facilities provided through public transportation agencies.

Openness in the infrastructure, meaning easy access to all necessary databases, allows customized fusing of information for each decision support application. There should be no more “swivel chair integration” of multiple physical displays, and no more need to support multiple communications channels to individual data sources. Openness also promotes coordination of decisions through easy interchange of decision outputs, some of which are advisories to travelers, and some of which are operational decisions to be coordinated between treatment, traffic management and fleet dispatching. Openness does not preclude justifiable access privacy or fees for service, and it is intended that many applications will be commercialized and financially self-sustaining. The open system requirements will be promoted through the National ITS Architecture. For openness, it is required that weather information not be “stovepiped” in the ITS, which is why the WIST System must not be a discrete subsystem of the ITS, but rather should be an integration of weather information into all relevant user services and subsystems.

The WIST System in the ITS is a vision for development. The WIST System does not intend to provide complicated systems where simple ones will do. It does intend to use technology to simplify and make more effective the interface between information and people. The WIST System infrastructure is largely in place and is continually being upgraded by the NWS. The functions that the WIST System applications need to improve include:

- Support to decisions with information from the common infrastructure that is specifically tailored by filtering, fusion and analysis.
- Improved decision making that uses statistical (risk) information about the uncertainties inherent in weather.
- Improved execution of decisions, especially by obtaining appropriate traveler responses to weather advisories.
- Coordination across multiple decisions that are made serially and in parallel by travelers, traffic managers and transportation maintainers.
- Evaluation of how decisions affect performance in the surface transportation system.

Centering attention on WIST System applications for surface transportation decisions separates the legitimate concerns of the surface transportation community from those of the NWS. The NWS generally cannot tailor its products to respond to the specific needs of applications, and the FHWA cannot take on any weather information production role. The WIST System infrastructure and applications integrate these domains functionally while respecting their institutional specialization.

WIST System Use

The WIST System concept expands the scope of the RWIS, that are focused on snow removal and ice treatment. The WIST System serves all decisions of all surface transportation decision makers where weather and its impacts are an issue. Decision makers include highway and rail operators, private and commercial travelers, transportation facility builders, incident response agencies and planners.

A principle of weather information and decisions is *scale*, in terms of the time horizon and spatial area involved. Larger scale generally means more uncertainty, that has to be considered explicitly in decision making. Categorizing decisions by their scale matches them to appropriate information sources. The meteorological scale categories of micro, meso/synoptic, and climatic are mapped to transportation decision scales called “warning”, “operations” and “planning”. At local scales, “warning” decisions depend on direct observations and uncertainty in weather and related road conditions can be reduced by investment in more environmental sensor stations. For decisions that have to be made with longer time leads, roughly beyond a half-hour, significant predictive uncertainty always has to be coped with. In these cases there is need for development of risk-based decision procedures, and fusion of information from different models and sources.

WIST System Needs

A workshop held by the Weather Team produced a list of WIST System needs from transportation and meteorological practitioners. The list contains needs for the WIST System, and needs for general programmatic support. The needs for the system further subdivide into component development, integration, and system support. This needs list is the basis for Weather Team action to achieve the WIST System vision.

Needs Analysis

The National ITS Architecture specifies a needs-based process leading to system requirements. This White Paper starts the process by identifying the issues needing further analysis:

- The appropriate level of investment in specialized transportation facility sensors, both fixed and mobile, and their integration with NWS observations.
- Better articulation of surface transportation needs to the NWS, by better identification of the deficiencies in use of weather information for transportation outcome improvement.
- The responsibilities for analysis, quality control and archiving of data as improvements in NWS products shift the boundary between infrastructure and decision support in applications.
- Better fusion of information for decision support, even with non-open system legacies.
- The production and use of probabilistic information to support data fusion and risk-decision making.
- Improved outcome evaluation for both system design and operations.
- Public versus private ownership and exploitation of information.
- The degree to which the NWS can be engaged in specialized surface transportation weather information, analogous to its engagement in aviation weather.
- The formation of a federal focus for surface transportation weather, to achieve the coordination existing among maritime, aviation and military weather programs.

Actions

The Weather Team can facilitate, but will not be the deployer of the WIST System. Regular federal-aid transportation funds are available to localities for research and deployment. The Weather Team will incorporate WIST System requirements into the National ITS Architecture as the technical framework of system deployment. The Weather Team will monitor developments, sponsor its own development projects, and deliver technical information and training through the federal ITS and other programs. The Weather Team has already funded an evaluated development and demonstration project, starting in 1997, and has compiled a synthesis of existing WIST-related projects and programs. Further projects are in the rural ITS budget.

The Weather Team intends to coordinate weather issues across the surface administrations of the USDOT. This will supplement existing maritime and aviation weather foci within the USDOT, that interact with the NWS and the Department of Defense on weather programs. The Weather Team will emulate the high-level, inter-departmental National Aviation Weather Program Strategic Plan by a Surface Transportation Weather Program Plan, that will coordinate goals and future activities among several agencies. This White Paper presents the public with the opportunity to comment and provide input to that plan.

Weather Information for Surface Transportation

Introduction

The Federal Highway Administration (FHWA) Weather Team was formed in 1997 under the Intelligent Transportation System (ITS) program of the U.S. Department of Transportation (USDOT). The team considers weather information needs of operators and users of all surface transportation modes. The team will coordinate federal actions and promote local deployments to meet these needs. This White Paper focuses on surface transportation decisions that need to be supported by weather and other information. Issues are identified and further actions by the team are recommended.

Results of the FHWA Surface Transportation Weather Information Workshop[1] have supplied the team with needs and possibilities for weather information, from both meteorological and transportation practitioners. Team findings have been given preliminary exposure through presentations to the Transportation Research Board[2], American Meteorological Society[3,4], and Standing International Road Weather Commission[5] conferences in 1998. The team sponsored an operational test starting in 1997 and has additional projects budgeted through the rural ITS program. The Weather Team seeks further comment from the public on needs for weather information in surface transportation and actions to address those needs. This White Paper and public comments will lead to plans for USDOT actions to realize the goals of the ITS program and of the FHWA National Strategic Plan.

Organization and Role of the Team

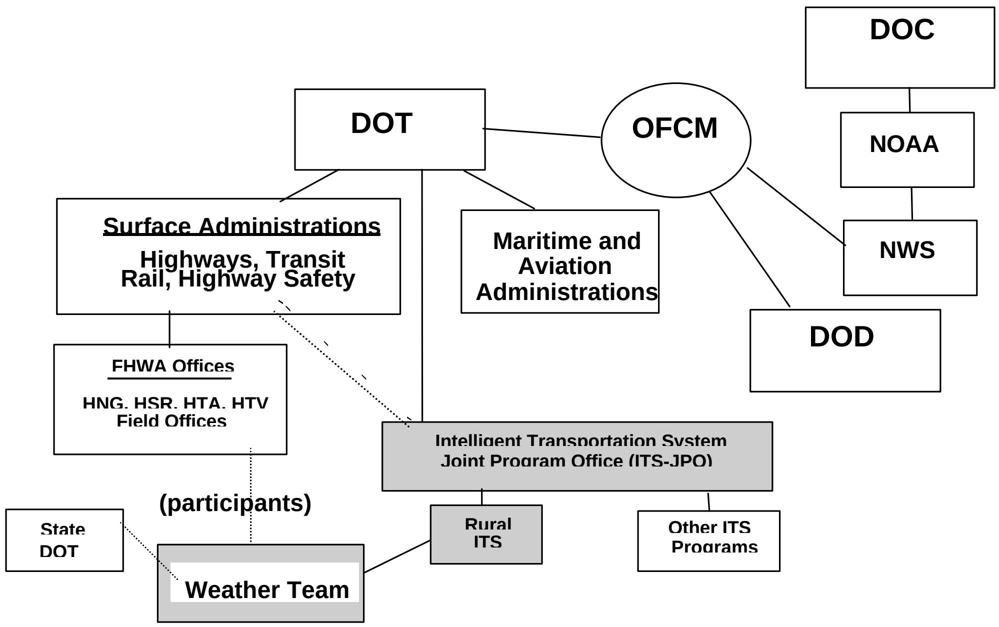
The team was formed as part of the rural ITS program under the ITS Joint Program Office (JPO). A mission of the team is to incorporate requirements concerning weather information into the ITS via the National ITS Architecture and its standards. The goals that frame this mission, and how this mission is to be carried out, are explained by the organizational context of the team, shown in figure 1.

The ITS JPO operates under the USDOT and has participation by the surface administrations of USDOT: the FHWA, the Federal Rail Administration (FRA), the Federal Transit Administration (FTA) and the National Highway Traffic Safety Administration (NHTSA). The FHWA has offices with active programs concerning road weather and these offices are represented on the Weather Team: Safety and Traffic Operations Research and Development (HSR), Engineering (HNG), Technology Applications (HTA), and Traffic Management and ITS (HTV). Also represented are the FHWA field organization, by a division (state level), and the FHWA constituency by a state DOT. Resources directly supporting the team come from the JPO and the

1 Proceedings, FHWA Surface Transportation Weather Information Workshop, June 17-18, in McLean VA, published July, 1997.
2 Pisano, Paul and Gary G. Nelson, Weather Information for Surface Transportation, Paper 981308, for the 77th Annual Meeting of the Transportation Research Board, January, 1998.
3 Pisano, Paul A., U.S. DOT Programs for Surface Weather Information, 14th Annual Conference on Interactive Information and Processing Systems, January, 1998, American Meteorological Society.
4 Nelson, Gary G., Surface Transportation Weather Information Decision Support and Meteorological Issues, ibid.
5 Pisano, Paul A. and Gary G. Nelson, Integrated Weather Information Systems: White Paper Findings, 9th Standing International Road Weather Commission, Lulea, Sweden, March 1998.

rural ITS program budgets. The team needs to coordinate other resources concerned with weather information in the other FHWA offices and in other administrations.

Figure 1: Weather Team Organizational Context



How the team will operate is based on two organizational facts: None of the USDOT surface administrations are operating agencies, and the responsibility for weather information is centered on the National Weather Service (NWS) under the National Oceanographic and Atmospheric Administration (NOAA) of the Department of Commerce (DOC).

The nature of the USDOT surface administrations, that the JPO inherits, stipulates the kinds of actions the team can undertake. Almost none of the ITS will be federally built or operated. ITS deployment will be by states, localities and the private sector. The federal-aid funds granted by the surface administrations can be used for ITS, but are not directed as such. The National ITS Architecture is the technical framework for ITS deployment. The ITS program sponsors research, operational tests and guidance resources toward development of the architecture and its “mainstreaming” into deployment planning and programming. This is the scope of actions that the Weather Team can take. States can undertake their own research programs, particularly using pooled federal-aid funding, and an example is the Aurora consortium that deals with surface transportation weather issues.

The USDOT has an interest in using weather information for surface transportation decisions to improve transportation system performance. The USDOT must separate its interest from the production of weather information that is the responsibility of the NWS. The NWS is the national provider of weather information, although there are many specialized weather information vendors in the private sector. The FHWA has been active in promoting specialized observations of weather associated with roadway conditions through the Road Weather Information System (RWIS) that also includes tailored vendor information. The distinction between general and specialized weather information is sometimes fine, and is one of the issues in defining a team focus. However, the team wants to delimit the need of the transportation community to produce weather information, while promoting *use* of ever-improving NWS products tailored to support surface transportation decision makers in the improvement of surface transportation performance. These decision makers include transportation system builders, operators, maintainers, travelers and shippers.

The surface administrations of USDOT are in contrast to the maritime and aviation administrations that have operational functions: the Federal Aviation Administration (FAA), the Maritime Administration (MARAD) and the Coast Guard. Particularly for aviation weather, there has been a longstanding and intimate cooperation between the FAA, NWS and the Department of Defense (DOD). These agencies have a cooperative observation program, and the NWS staffs aviation weather facilities. This close cooperation has been through the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM). This inter-departmental coordination is a model for surface transportation to follow, and the Weather Team is already working through the OFCM on joint agreements between the USDOT and the NWS.

Perspectives of the Weather Team

The contents and focus of this paper follow from the scope and mission of the Weather Team. The technical and operational research underlying the paper also lead to some perspectives and conclusions:

1. The technical focus is on surface transportation decisions, that mediate between weather information and actions affecting transportation outcomes of safety, efficiency, user satisfaction, environmental quality and cost.

2. The programmatic focus is on actions within the scope of federal surface transportation agencies, including funding of research and operational test projects, dissemination of technical and operational guidance, and development of the National ITS Architecture.

3. The NWS is the public provider of weather information, but cannot "tailor" its products for every transportation decision maker. Transportation agencies generally are customers for, and not producers of weather information.

4. The boundary between the NWS and transportation agencies is bridged by "decision support". This generally involves the selection and fusion of several kinds of information, and converts "weather" information into "road condition" and other transportation system attributes. Decision support may include getting specialized observations at or near transportation facilities. NWS information goes into decision support. The NWS should receive the specialized observations, and feedback on how well NWS products meet transportation needs.

5. The role of private vendors in decision support is recognized and respected. They tailor NWS meteorological products for specific uses, develop information systems, and generally provide the means to bridge the NWS and transportation domains.

6. The demand of transportation decision makers for "better weather information" has to be specified by a "scale" concept, concerning the time lead (horizon) of a supported decision, and its spatial area. Investment in more and better observations directly improves short-horizon information, but has diminishing returns at horizons where numerical forecasting models are required. The transportation sector is going to have

little effect on the uncertainty inherent in the forecasts provided by the NWS, and the more important issue is to characterize and use that uncertainty in risk-based decisions.

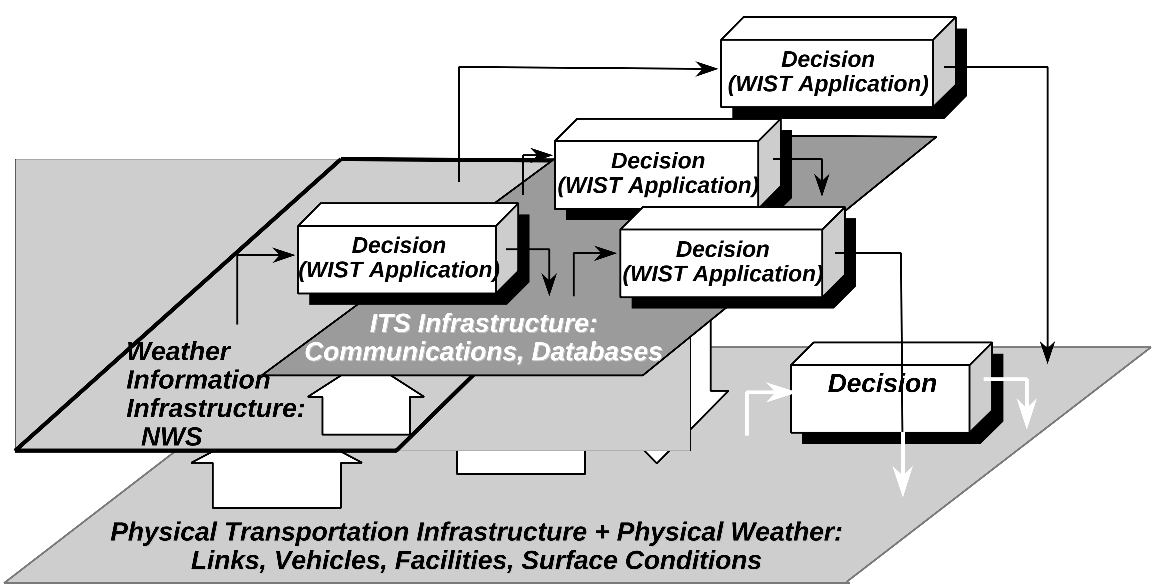
7. The "Weather Information for Surface Transportation (WIST) System" labels the concept of weather information being accessed and used in the ITS. Once in the ITS, weather should not be segregated from other kinds of information. Since so many ITS decisions and subsystems use weather information, the WIST System is not a separable part of the ITS.

8. Improved outcomes in the surface transportation system are the measures of the WIST System, not the quality of weather information. Better evaluation information is needed to define the relation between weather information quality and outcomes.

The Structure of the WIST System

The WIST System will not be a single set of hardware, software and communications. It will be embedded in the ITS. The system is best thought of in terms of decision threads—the process of using weather and other information to affect the surface transportation system. Focusing on these threads, that differ for each kind of decision maker in each decision context, will reveal the kind of decision support needed, and from this will come detailed requirements for the ITS. Figure 2 shows a layered structure, of decisions as applications supported by both a NWS and an ITS information infrastructure. The information comes from, and decisions act on, the physical infrastructure of the transportation system and its environment. Conceptually, the "WIST System" is the set of decisions using weather information. Physically, the WIST System is distributed throughout the ITS and receives information from the NWS system.

Figure 2: The "WIST System" and its Infrastructures



The NWS weather information structure observes the physical layer and disseminates processed information to characterize the weather (meaning the state of the atmosphere) and “meteors” from it (meaning forms of precipitation). Since all decisions are prospective, all decision support information is used as predictions. Finer distinctions between weather observations, “nowcasts” and “forecasts” have to do with scale, and do have significant technical ramifications. Different scales of decisions must use different information processing, and this is represented in the variety of NWS products and processes. There is no single source of weather information, and no single criterion for its quality.

The ITS infrastructure measures and controls the state of the surface transportation system and its intermodal interfaces. Inputs to the ITS infrastructure can come from the physical infrastructure, from the NWS, or from decisions (e.g., advisories and controls). All the outputs (controls, which are effected decisions) act on the physical infrastructure.

A WIST System application is defined as the decision support interfaces within the ITS to decisions that uses weather information. The figure shows a variety of WIST and non-WIST decisions. The information flow through a WIST System application (decision thread) is:

1. From the physical infrastructure
2. Through sensors that create observational data
3. Into the information infrastructures
4. To applications that support, effect, coordinate and evaluate decisions
5. Back into the information infrastructure (e.g., advisories to be disseminated to other decisions) or into the physical infrastructure (e.g., a travel or road plowing decision).

Most decisions are made by direct observations of the infrastructure and actions on it (e.g., driving) and do not use ITS for information processing. A subset of ITS-supported decisions are supported by WIST applications if they incorporate weather information from the NWS or from ITS (including the specialized weather and road condition sensors).

A WIST System application generally will not be distinct from other ITS applications. Travel planning, vehicle navigation, fleet dispatching and traffic management require other kinds of information besides weather and will use communications and applications that do not segregate these kinds of information. Treating weather like a separate kind of information, going through separate channels to separate displays is called “stovepiping”. It leads to “swivel chair integration” where it is left to the decision maker to access and integrate information from different sources. WIST system applications should access the open ITS and NWS infrastructure to integrate the information fully for each decision. The user comes with one question to one source to get an answer. This open systems principle is inherent in the ITS, and is achieved by the National ITS Architecture and its standards.

All kinds of decisions that use weather information are to be supported by WIST applications. The RWIS has primarily supported highway maintenance decisions dealing with snow removal and ice treatment, and these decisions will be incorporated into the WIST System. The WIST System additionally will serve management of all surface modes that involve traffic control, route restrictions, planning, scheduling, routing and dispatching. The WIST System will serve travelers and those who depend on the arrival of passengers or goods. The WIST System will serve planners and operators of events and activities that relate to surface transportation, such as recreational, construction or production events.

In terms of processing information, scale is more important than the object of the decision. A driver decision or advisory for an immediately hazardous road condition must be based on direct and local observations of speed, visibility, following distance, road departure, road icing, etc. Long-horizon planning, as for the stocking of equipment or construction planning, must use climatological information. In between are new challenges for the fusion of the spectrum of information from point and volumetric observations (e.g., doppler radar), through small scale numerical prediction models, to global predictions.

The measure of the WIST System is not in its hardware, software, communications or quality of weather information. It is in the improvement of the transportation system in terms of fewer crashes, less delay, less environmental impact, more satisfaction of transportation users, and less adverse environmental impact. There is a practical challenge to setting this the goal. There is large uncertainty in how information system shortcomings result in outcome deficiencies, and there is always uncertainty in measuring how individual decisions affect the transportation system. In some cases, such as chain collisions in bad visibility, it is obvious that weather information is not the problem—it is the translation of known hazardous conditions into safer driver behavior through persuasive advisories. This is the "decision effecting" end of the WIST System. The WIST System has to improve the evaluation feedback of how decisions affect outcomes. This involves statistical analysis and has much in common with uncertain weather information that has to be statistically characterized. Individual decisions that commit resources, and the investment decisions in developing the WIST System are both risk decisions.

Activities of the Weather Team fit the general ITS program categories of Development, Delivery and Deployment. Development includes research and demonstrations of promising solutions. The Weather Team began in 1997 the funding of an evaluated demonstration with the Foretell™ public/private consortium in the mid-west. Delivery consists of technical support and information dissemination, for which the Weather Team has already compiled information on projects and programs of use in realizing a WIST System[6]. Regular federal-aid funds can be used for deployment of proved system components, and the Weather Team intends to ensure the eligibility of such deployments. However, the bulk of system deployment funding is expected to come from local and private funds, including fully market-supported applications for transportation system operators and users.

Organization of this Paper

This paper has six parts:

1. Transportation Outcomes and Weather Information.

2. A Vision for the WIST System, including its structure and interfaces.

3. Scenarios of WIST System use that illustrate the breadth of application and elements of decision making.

4. Needs of decision makers and of system support that drive a program to realize the WIST System.

5. Analysis of the needs, that links them specifically to program actions.

6. A preliminary list of Actions to be taken.

[6] Weather Summary and Synthesis Report, Eileen Singleton, FHWA, McLean, VA, June 1997.

This paper is being circulated for wide review, to build on inputs of the Workshop and conference presentations. The Weather Team will learn from these inputs, and progressive results of sponsored projects, to create and update a Program Plan that will schedule and budget for further activities.

Transportation Outcomes and Weather Information

The goal of the WIST System is to improve surface transportation outcomes through decisions. Transportation decision making is never concerned solely with weather information, and the outcomes are from a complex process involving the interaction of many decisions and natural conditions on the surface transportation system.

Decision Outputs and Transportation Outcomes

The ITS program operates under the Government Performance and Results Act (GPRA) that specifies evaluative feedback procedures. The GPRA makes a distinction between outputs, that are the effected decisions, and outcomes that measure performance of the transportation system. The ITS program has a working set of outcome measures[7], that have been restated for the rural ITS program[8]. The following outcome measure list synthesizes these sources:

General ITS Outcome Measures

1. Safety, measured by crashes and fatalities, and security
2. Travel time, of passenger trips and for deliveries
3. Mobility and convenience
4. Throughput, meaning ability to handle more travel volume but without physical facility expansion
5. User satisfaction with transportation services
6. Environmental conservation (including energy and air pollution)
7. Costs of transportation, and derived benefit-cost or efficiency measures (other measures achieved per invested cost)
8. Economic vitality and productivity

Transportation decision makers cannot change the weather, but they have three basic options to control outcomes through outputs that are decided with weather information:

- Treat the results of weather on the transportation system (example, plow snowfall and treat for ice formation or pump flooded areas)
- Cope with the results of weather (example, by closing routes, putting chains on tires, altering travel or rescheduling activities)
- Respond to ameliorate bad outcomes from weather (example, issue advisories, patrol severe weather areas for victims, or repair storm damage)

The weather conditions that provoke these responses are atmospheric conditions interacting with surface and subsurface conditions. Precipitation or condensation on cold pavement creates the snow and ice problem. Heavy precipitation, fog, blown smoke or dust, and glare impair visibility. Winds affect vehicle stability, and can damage structures. Precipitation and high watercourses flood roads and tracks and cripple inland waterways. Different outputs are

[7] Data Needs for ITS Program Assessment, Peters, Bolczak and Shank, 1997.
[8] Advanced Rural Transportation Systems (ARTS) Strategic Plan, USDOT, December 1996.

appropriate to these conditions and outputs such as pavement treatment, speed-advisories, and travel limitations for snow and road icing should be coordinated for the best outcomes.

The Challenge of Evaluating Outcomes

It is almost impossible to have a fully controlled experiment that could measure the effects on transportation system outcomes by improvements anywhere along a thread from weather information to decisions, to outputs (individual decision effects) to outcomes. Many variables enter into an outcome, some of which are decided and some of which are "states of nature" like weather. The challenge is to use good evaluation practice, adequate evaluation investment, and the data capabilities of ITS to meet the goal of reliable outcome evaluations. Evaluation needs to be done as part of WIST System development planning, to indicate where the deficiencies are in the decision process. It needs to be done operationally so that decision makers are always learning improved ways to make decisions.

One evaluation problem lies in how outputs are defined. An example is snow removal and ice treatment decisions. Decisions of where and when to treat, followed by dispatched crew activity, result in an output measure of pavement clearance and tractability, called the pavement level of service (LOS)[9]. Pavement LOS will affect all the outcome measures in some way. However a WIST System evaluator might argue that maintenance truck dispatching and driver competence are not at issue, and then leave the output at the manager's directive of where the trucks should be at what time. Others might argue that the weather issue ends at the pure weather information in decision support.

The position of the Weather Team is explicit: Evaluation must link weather information to surface transportation outcomes, in a way that continually moves decisions and the systems that support them toward an optimum with respect to budgetary and other constraints. Important among the constraints is the inherent uncertainty of weather forecasts.

Expected Improvements in Transportation Outcomes

Despite the existing shortcomings of evaluation, expectations of outcome improvements motivate WIST System development.

Safety

Weather is implicated in crashes, structural failures and exposure fatalities, while impeding emergency response. Weather is the cause of major disasters that both impair transportation facilities and require them for response and evacuation.

The tree diagram below shows crashes and their relation to weather conditions[10]. Fatal crashes in adverse weather conditions are 18% of all fatal crashes, and the injury crashes in adverse weather are 21% of all injury crashes. However, weather, and information about weather, as causal factors are less certain. Also, exposure measures are too poorly known (e.g., all vehicle miles

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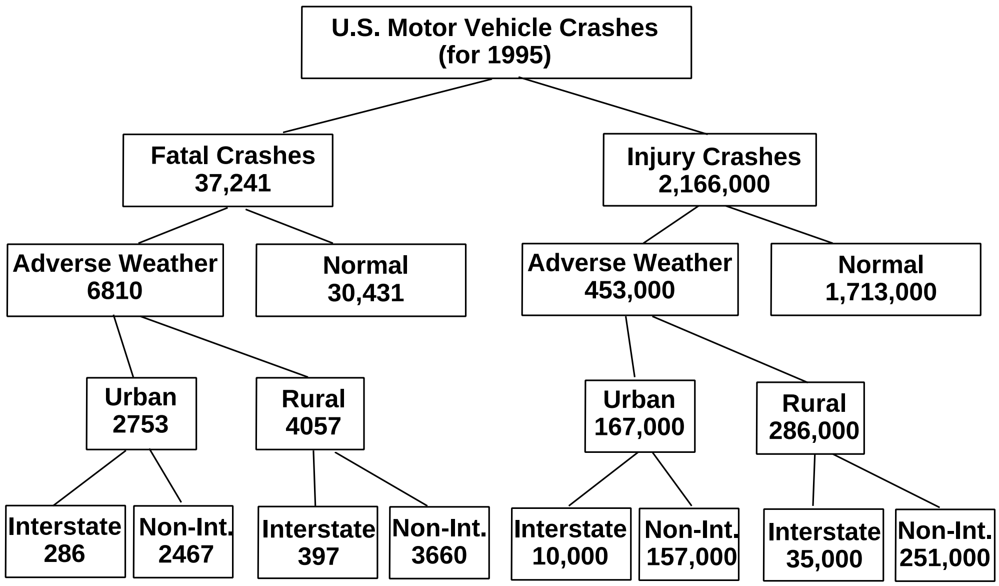
[9] Manual of Practice for an Effective Anti-Icing Program, Publication FHWA-RD-95-202, FHWA, June 1996.

[10] Based on Fatal Accident Reporting System (FARS) and General Estimates System (GES) database tabulations. Adverse weather includes wet, snow/slush or icy pavement and rain, sleet, snow and fog atmospheric conditions. The rural and urban categories are given directly in the FARS, but are estimated from indirect variables in the GES, and may not correspond exactly to FHWA facility definitions.

traveled with varying pavement LOS or visibility conditions) to derive relative crash frequencies in normal and adverse weather. Numerically, the non-interstate routes are the major concerns.

Figure 3: Vehicle Crashes and Adverse Weather



Crashes are rarer events than adverse weather, so it is obvious that adverse weather does not by itself cause crashes, and more crashes occur in non-adverse weather. It can be assumed that even perfect weather treatment or information will not address all the crash causes, even in adverse weather. However, information and advisories, including those that respond to weather, can impact all crashes.

The nature of some weather-related crashes indicates the challenge to information-based improvements. For chain-collision crashes that occur in fog banks, or where roads are obviously slick, the weather conditions were obvious to the drivers. Information systems cannot improve the immediate perceptions of weather conditions, but they may affect behavioral response to those conditions, or prompt management decisions to deny access to unsafe routes. In either case, a risk-based approach is required. An advisory, like a variable speed limit or warning using variable message signs (VMS), can shift the drivers' risk perception of the tradeoff of speed for safety. This only works if the safety risk is made more credible than the drivers' own perception. This depends on the uncertainty in the weather or surface condition information and signs saying "bridge freezes before road surface" probably are ineffective. The highway operator faces a risk decision to balance false alarms (unnecessary delay) versus missed alarms (unwarned crashes). In the case of conditions requiring road closure, a sequence of state, toll road and local jurisdictions must be coordinated. Similar coordination must apply to the sequence in which links are treated for snow and ice.

Crashes are linked to fatality and impairments from injuries via after-crash exposure and response time. Cold and shock can increase mortality. Response times can be lengthened in adverse weather, and this is more critical in rural areas. Weather information effects on road treatment and traffic management may improve response times, while the reduction of crashes that do occur in adverse weather may more than proportionally reduce fatalities and long-term injury impairments. Weather information regarding plumes and runoff can play a role in responses that reduce Hazmat crash consequences.

Travel Time Delay and Throughput

It is probable that the WIST System will have its largest benefits from reducing delay and congestion costs. But even preliminary statements on the magnitude of effects are inhibited by the inability to separate weather effects from "normal" delay and congestion.

Delay can be caused by the decrease in "safe" speed independent of traffic congestion effects, such as on icy roads when there is a danger of skidding, or in high winds with vehicle instability. Estimating the amount of this delay is difficult because of the lack of data on the number of vehicle miles traveled (VMT) exposed to the various weather and surface conditions. With traffic congestion effects, the estimation problem is even more difficult. In congestion, delay is very sensitive to the changes weather can induce, and congested travel may be associated with other causes such as work zones and crashes. Traffic level of service (LOS) is an indicator of congestion delay, and reliable estimates of weather, separate from other effects, on traffic LOS are still lacking.

Weather affects traffic LOS through lane capacity or through driver behavior and vehicle response. Traffic LOS is defined *empirically* for freeway links as traffic density (vehicles per mile). For links with intersections (signals, stops signs, or any stop-and-go flow) it is defined by queue formation. *Analytically*, traffic LOS is derived by relating density and speed to the v/c ratio, which is volume (vehicles per hour) over "normal" capacity. Capacity is empirically set as a percentile of observed throughput (volume). As the v/c ratio increases from 0 to 1, traffic LOS worsens from A (low density, free flow or no waiting queues) to F (jammed traffic, indefinitely growing queues). Weather reduces capacity, or achievable throughput, when snow, water, slope failures, blown/waterborne debris, crashes or structural failures physically obstruct lanes. This will act on traffic LOS through the v/c ratio. Weather also acts on traffic LOS through the density and speed relations. Icy or wet pavements, poor visibility, glare, and high winds creating vehicle instabilities will all tend to reduce speeds at a given density. For stop-and-go travel at intersections or with congestion, the weather effects can be primarily through reduced startup acceleration and reduction of (or just the risk of reduced) braking deceleration.

Treatment, especially in congestion, must be combined with advisories on closures and residual hazards, which involve traffic management and affect travel planning. For congested traffic, treatment itself is a congesting effect. As the LOS approaches level D and worse, the relation between delay and anything affecting effective capacity or the density-speed relation becomes quite sensitive. Therefore "rough" estimates of the weather effects are not useful in the congestion regime where most delay will occur. Conversely, the effectiveness of removing even small volumes of traffic, or preventing crashes, is very great in congestion. This is the reason why the WIST System must pursue its largest potential benefits by integrating maintenance, traffic management and travel planning decisions related to weather.

User Satisfaction

User satisfaction is a subjective rating of trips and services that may include other outcome effects. Subjective assessments are best for probing how the WIST System affects decision makers, as part of the thread toward improved outputs and outcomes that must be measured objectively. Decision makers will be dissatisfied if not forewarned about weather and its impacts on transportation operations, and cannot cope, treat or respond effectively. Although blame for this tends to be leveled at uncertain weather forecasts, the problem can be in any of the decision support attributes, including the automation-human interface. Dissatisfaction with decision execution can indicate inadequate organizational structure or communications, including poor human interfaces with those receiving directives and advisories.

Some survey data indicate travel conditions of concern to traveler information systems, and weather rated in the top 8 in one study[11]. Projects such as the Advanced Transportation Weather Information System (ATWIS) in North and South Dakota are showing good use of cell phones and the Internet for route-specific weather information, with usage peaking during storms. This shows a demand, but the dimensions of usefulness have to be assessed more fully. The Iowa DOT has already assessed user satisfaction with their kiosks for road condition and weather information, and the Foretell demonstration will survey all users on baseline and advanced information systems.

Environmental Conservation

Excessive salting for ice treatment is a watershed pollution problem. Weather is an important factor in air pollution episode or Hazmat spill management. Failure to consider climatic conditions in facility design degrades the environment as well as decreasing safety and throughput.

The excess-salting problem has been well characterized as part of RWIS analysis. Between 15 and 20 million tons of salt (NaCl), and minor amounts of other chemicals, are used annually[12]. Air pollution and erosion/runoff problems have obvious relations to weather. Environmental Protection Agency (EPA) air quality model research indicates the sensitivity of pollution forecasting to weather data quality, but the relation of weather information to the effectiveness of control strategies, either strategic or episodic, is almost unknown.

Costs of Transportation

Costs are associated with adverse outcomes, but also with the information systems and operations needed to improve outcomes. The issue is to achieve economically efficient outcome improvements, by making decisions more efficient and effective.

Treatment cost is relatively well characterized. Snow and ice treatment costs for highways are $2.1 billion per year, with $700 million of that for chemicals[13]. Costs of weather in terms of infrastructure damage are estimated at $5 billion per year[14]. Costs of construction and maintenance delays, precautions or spoiled work are not known. Other vehicular, or transportation operator costs due to weather, including those of weather information services, are not comprehensively known.

The investment costs of the WIST System and other ITS components need to be evaluated along with outcome effectiveness to optimize costs versus benefits. At present, the WIST System is focusing on decision support and execution because the NWS and the ITS program generally are already focusing on the information inputs and their communication. It is believed that decision support is the deficiency that will have the most cost effective leverage over the huge transportation system costs of adverse outcomes. Specialized RWIS-type sensors are expensive, and will have diminishing returns to outcomes so that the optimum level of deployment still needs to be determined.

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[11] JHK and Associates, Rural Applications of Advanced Traveler Information Systems, for the FHWA, August 1995.
[12] FHWA data from the Office of Engineering, HNG-21. Applicable to ca. 1995.
[13] Ibid.
[14] Ibid.

Weather Information Market Coverage

Despite the uncertainty about the effects of weather information on outcomes, it is clear that the information has to get to user markets if it is to have any effect on decision making. The market is transportation facilities and tripmakers at risk from adverse weather effects.

It is known that the U.S. has a large number of severe storms per year: about 10,000 severe thunderstorms, 1000 tornadoes and 1000 flash floods[15]. The percentage of time that any area is subjected to any unusual weather is highly dependent on local climatology and will vary over climatological cycles. Good archives of weather data exist only for a sparse network of NOAA surface observations, mostly at the one major airport in a region. Experience from a Seattle analysis of crash reports versus weather observations indicates that the point data are inadequate to characterize even the nearby road network. Pavement conditions further require much inference from the available NWS "surface" observations (i.e., atmospheric conditions close to ground level). RWIS data are mostly too sparse to give the weather-risk assessment of specific travel and route markets, but the opportunities for analysis with adequate data are increasing.

The entire surface transportation network at risk from adverse weather is known, and as of 1995 includes:

- 3,912,226 miles of public road and street[16]
- 108,264 miles of intercity Class 1 railroad[17]
- 25,777 miles of inland waterway[18]
- 6,185 route miles of urban rail transit (heavy, light and commuter)[19]

The distribution of usage by route mile is highly skewed. Half of the highway VMT is carried on just 5% of all route miles, including the Interstates and urban arterials. There are 3 million rural highway route miles, but just 4% of this, or 130,000 miles of Interstates and principal arterials, carries 47% of all rural VMT[20]. These routes will also carry the bulk of long-trip miles, and are generally the only rural routes where traffic will approach congestion.

The distribution of traffic by route miles suggests priorities for ITS and WIST System deployment. RWIS sites and route-specific information are focusing on the Interstates and primaries. This hits the most trips per linear mile and most of the congestion. But in contrast to delay, a substantial number of crashes do occur off the main routes, and the large, low volume route mileage takes proportionately large treatment resources.

Mobile sensing may be the most efficient means of observation off the main routes. Using maintenance vehicles is desirable, but this only covers where vehicles are already dispatched. If mobile sensing from travelers is feasible, all traveled routes can be monitored, although this will encounter communications coverage problems in remote rural areas, and data volume problems in urban areas. Mobile sensing on transit, school bus and patrol vehicles is a good strategy that will cover important routes independently of treatment dispatching.

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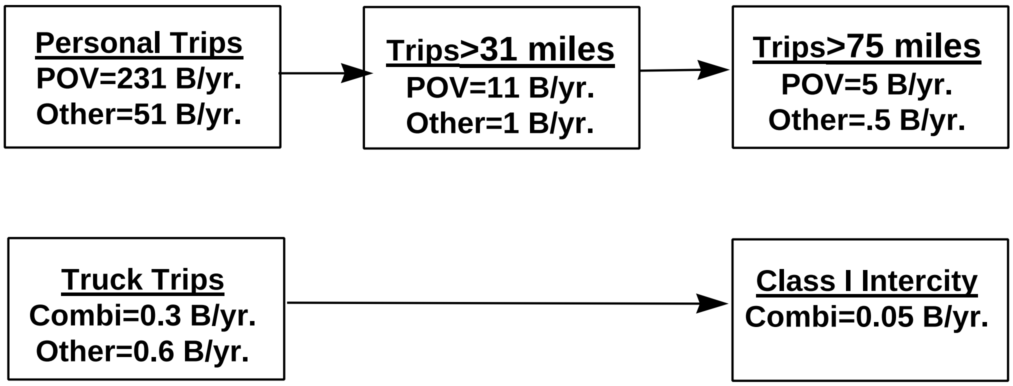
[15] NWS figures, from briefing at the April 1997 Dissemination technology Conference.
[16] Table HM-12, Highway Statistics, FHWA 1995.
[17] Table 1-1, 1997 National Transportation Statistics, Bureau of Transportation Statistics, USDOT.
[18] Ibid.
[19] Table 1-5, Transportation Statistics Annual report 1997, Bureau of Transportation Statistics, USDOT.
[20] Tables HM-20 and VM-2, Highway Statistics, 1995, FHWA.

All trips form a market for weather and other travel information. The annual trip market in the U.S., with some indication of trip distance, is shown below[21]:

Figure 4: U.S. Personal and Commercial Truck Trips, 1995



The personally operated vehicle (POV) trips shown are vehicle-trips (not person-trips). The “other” trips are person-trips in a shared mode (bus, taxi, train, and plane), and the great majority of these are by a surface mode. A fraction of the “other” trips therefore includes the trips of shared-mode vehicles whose managers can use weather information for fleet dispatching. Truck trips are in combination (“combi”) rigs with separate trailers or various “other” trucks (single units, but excluding personal vehicles).

The WIST System must deliver the right information to meet the market. Credible and useful information must be available at the right time and cover the right area, in a manner meeting constraints of the human decision maker. The challenge to the WIST System is to target information effectively to those most at risk from weather effects. Trip length has some relation to the type of weather information to be accessed. For short trips, a “look out the window” has much utility. However, urban commuters need network-wide information for their trip planning and rural residents with limited route choices may have a critical need to know whether nearby links are flooded or still snow covered. Long-distance trips are a small fraction of all trips, and truck trips are a small fraction of all long trips, but this still leaves 5.6 billion trips per year of 75 miles or more. The long distance market needs information at varying horizons along trip itineraries.

[21] Personal trips are from the 1995 National Personal Transportation Survey, online database. Both day trip and period trip files are combined. Truck trips are derived from 1995 truck vehicle miles traveled in the 1997 National Transportation Statistics. Combination truck trips are derived from a 400 mile/haul factor estimated across carrier types from the 1994 Financial and Operating Statistics, Motor Carrier Annual Report, ATA. A 100 mile/haul factor is used for other trucks. The Class I intercity trips are from Summary Table 1, ibid., using vehicle miles and a 420 mile haul length.

A Vision for the WIST System

The vision for the WIST System includes what its users need, and the characteristics of the system to meet those needs.

Vision Statement for the WIST System

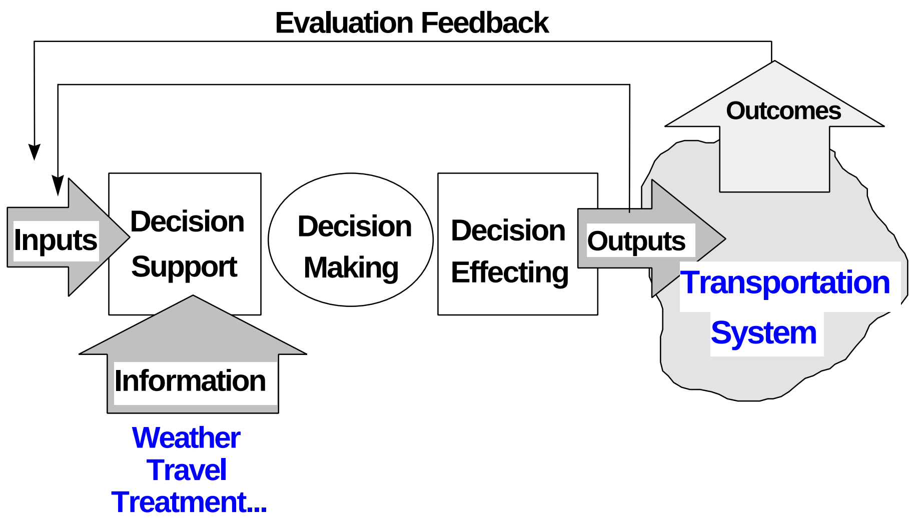
Transportation system operators and users have readily available weather information that is accurate, reliable, appropriate and sufficient for their needs. The resulting decisions effectively improve the safety, efficiency and customer satisfaction of the transportation system.[22]

Improved support for weather-related surface transportation decisions evolves through locally adapted applications that are integrated into a system with an information infrastructure that is national, and international. This evolutionary process occurs by decentralized, public-private action that is needs-driven and market-driven, but in a coordination framework that includes the National ITS Architecture. This framework allows decision makers to share an open system for obtaining weather information appropriate to each decision, and for coordinating the resulting decisions for maximum effectiveness. Decision makers measure their effectiveness in improving the performance of the transportation system, and use these measures to improve how decisions are supported, made and effected.

The WIST System: Context and Decision Threads

The WIST System connects infrastructures via multiple decision threads. Fulfilling the WIST System vision depends on improving processes in the decision thread, the interface with the information infrastructures, and the coordination of decision outputs in the physical transportation infrastructure.

Figure 5: A WIST System Thread--From Information to Outcomes



[22] This essential paragraph of the vision is a composite of vision statements proposed at the Workshop.

Figure 5 shows one decision thread, its functions and interfaces. Several decision threads operate simultaneously, for different people and agencies. The input is a decision to be made. The output is an allocation of information or other asset that eventually effects an outcome in the transportation system. The WIST System operates in a context of resources and constraints. One resource is weather and other information used in the decision. Also included are the ITS communications capabilities, materials, staffing, funding and training.

Note that the thread follows decisions to outcomes, and back through evaluation. The WIST System applications are along this thread, and there are many threads. The system *uses* resources like information and these are in the infrastructure to the WIST System. There is one common infrastructure that is shared by the applications.

The converse of resources is constraints that are also part of the context. These may be by law, policy directive, or physical capability. The physical laws of weather lead to its inherent uncertainties over space and time (lack of predictive information). This uncertainty can be reduced by more observational and dynamical information, but the economics of this leads to diminishing returns as the space and time scale is expanded. Institutional constraints, including staff and budgets, can be eased, but the question is still the benefit-cost of doing this. It is generally easier to make an efficiency case (more output for less resources) than it is to make a benefit-cost case (optimal outcomes).

Three functions occur along the decision thread:

- Decision support tailors external information to the decision input. This usually involves:
  - Filtering as selection from a vast amount of external information, and also error reduction by "smoothing" the information.
  - Fusion of disparate information to match the decision needs.
  - Analysis, meaning some degree of information transformation into the decision.
  - Information presentation, usually as display to a human, compatible with the decision maker's operating environment and information capacity.

- Decision making transforms the presented information into a prospective action. Therefore, predictions are inherent. Decision making can be automated, but in most cases it involves a human. Decision making under uncertainty involves risk (probabilities of outcomes via uncertainties in the information on the weather and the transportation system).

- Decision effecting transforms the decision into its output action. The action can be an information transfer, a control action, or the allocation of some physical assets.

Decision evaluation is a feedback of the decision thread. Evaluation information that comes from the transportation system outcomes, rather than more "upstream" outputs, should be shared among the many decisions on the transportation system. Therefore, evaluation information will often enter decision support from an information infrastructure (the ITS).

Most of the hardware and software associated with information systems is in the decision support function. This function is the boundary between the information resources and the decision proper. This function is the institutional division between what is properly an NWS concern of weather information infrastructure, and what must be tailored within a specialized surface transportation domain. This is also where vendors take over in providing specialized decision support. This boundary can shift with changes in what the NWS provides or what the WIST System demands. For instance, NWS dissemination of higher resolution meso-scaled forecasts and products such as doppler radar observations are displacing former vendor products. Vendors or Information Service Providers (ISPs) as they are known in the ITS lexicon, may be the conduits for NWS products.

Uncertainty, Statistics and Risk Decisions

Uncertainty is an essential issue in the WIST System decision thread. It is rarely addressed in transportation decision support or decision making. For this reason, there is a tentative conclusion: <u>WIST system improvements focused on risk in the decision making process, including in outcome evaluation, can be among the most cost-effective and cost beneficial</u>.

Uncertainty is inherent in all decisions because they necessarily use past data for future actions. Uncertainty comes from limits on factually measuring the past, such as having few or errored observations, and in the applicability of the past to the future. Uncertainty is significant both for weather and other transportation system variables, and depends on scale—the spatial extent and time horizon[23] covered by a decision. Weather is at least determined by natural dynamics, but the transportation system mixes atmospheric, surface and vehicle conditions with decisions by many people. This leads not only to prospective decision uncertainty, but also to retrospective uncertainty about the effects of one decision on the outcome.

Uncertainty, meaning lack of perfect information, cannot be eliminated. Its significance is relative to the possible variations in the outcome. These variations are measured statistically, as variance or standard deviation. These variations are a function of the uncertainty in all the processes leading to the outcome, starting with information resources but including the outputs (e.g., people not doing what they are directed to do, mechanical failure, etc.). If the relation of each source of variation to the outcome variation were known, it would be possible to make an economic decision of how to reduce the variation components. There are diminishing returns to uncertainty reduction, and the uncertainty can be economically optimized but not eliminated. Part of the WIST System development task is to approach this optimum, and the research to do this can be very cost effective in leveraging outcome benefits. The practical problems in doing this are challenging.

The WIST System must cope with remaining uncertainty in decision making. Again this can be very cost effective in leveraging benefits. The problem is this: Lacking the effort to provide statistical information on outcome variation factors, and lacking knowledge of what to do with it, decision makers substitute point (certain) values for decision factors. Without statistical information, these points are often chosen in a <u>biased</u> way from the uncertainty range. Common examples are the prediction of project schedules and budgets (usually overruns) or performance (usually deficient), where the bias is usually toward optimism. In the WIST System case, the costs include crashes (e.g., a bias for speed), excessive expenditure in road treatment, or a bias toward false or missed alarms in traffic management (e.g., road closures). Regardless of the amount of variation, achieving the best outcome over some statistical ensemble of decisions requires the statistical information on decision factors. "Best" may be defined as an optimized

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[23] Horizon is defined as the time interval between the observational information supporting a decision, and the future time when a decision has an effect on outcomes. If a traveler wants information on a road that will be reached in an hour, the horizon is at least an hour. For weather information, the additional time will depend on the cycle time for weather observation and prediction.

expected value, or as meeting certain "risk thresholds" (e.g., no more than 5% of icing cases where treatment failure leads to ice bonding to the pavement, or storm cases where schools failed to send pupils home and they were stranded at school). These threshold cases clearly show the role of statistical information.

The issues of statistical information for risk decision making go well beyond weather, but the NWS deals explicitly with such information, and it needs to be used better in decision support. The same applies to statistical analyses used in outcome evaluation.

The NWS runs forecast ensembles, using different models as well as distributions of observations. Another principle of risk is that a composite forecast (e.g., a mean value) is generally more reliable than using any one model. The ensembles also yield the distributional information desired across the models. The Quantitative Precipitation Forecast (QPF) is such a distributional product, disseminated as color-coded spatial areas where there is a stated probability (risk) of precipitation exceeding a given amount.

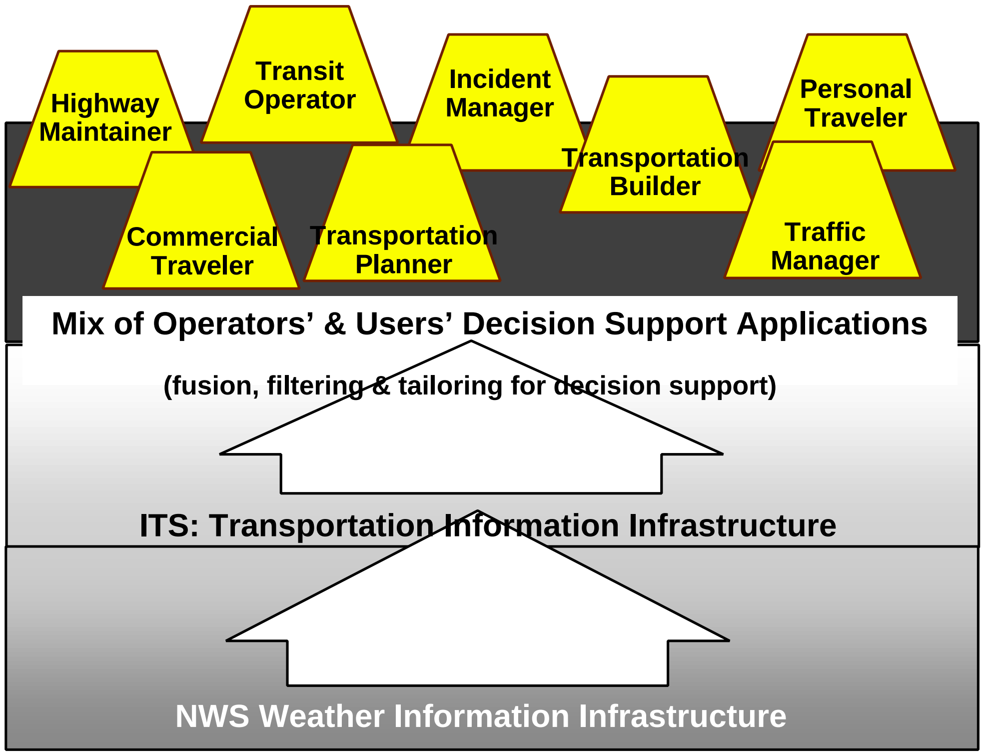
Statistical decision principles are also used for weather observations, to reduce the error of the ensemble of observations from that of individual sensor error. This is the statistical smoothing process used in "assimilation" of a set of measurements that have known error distributions. There is a tradeoff in this process. Smoothing suppresses what might be real local variation (e.g., a severe convective storm near one sensor) in favor of "averaging" toward a set of observations. This is where having more, and more precise, sensors still pays off. The same principles need to be applied to specialized transportation sensors, and this applies not only to environmental sensors, but also to ITS estimation problems such as detecting incidents from traffic flow information. Further, by assimilating RWIS-type observations with the pool of NWS observations, some cross-checking leading to detection of calibration and repair problems can be achieved, without more inspection resources.

Thinking in terms of statistics, statistical filtering and risk-decision making is therefore essential to the WIST System and to the ITS. These approaches can be built into systems, and are essential to any kind of data fusion that requires reliability weighting of information. However, most people have a hard time comprehending statistical information, or making formal risk decisions. The issue is the degree to which this can be built into software and hardware, toward automated decisions, and the degree to which humans must participate. With uncertainty, judgment can still be valid, but needs to make maximal use of available information. The mix and interface of human versus automated information processing is a major system design issue, and needs more information on human factors.

Openness and the ITS Infrastructure

The figure below shows WIST System applications serving many kinds of surface transportation decision makers. This diversity rest upon an infrastructure of information, from both the NWS and the ITS. The connection from infrastructure to decision maker is via the decision support process within the applications. The schematic of layering in the figure is meant to distinguish common, and general-purpose, information and communications utilities in the infrastructure from tailored and decision-specific applications. More detailed layer decomposition is fundamental to the technical concept of open systems.

Figure 6: Layering of the WIST System



The deployment of open systems is a general goal of the ITS, being pursued through the National ITS Architecture and its standards. An architecture is a system structure, including a layered decomposition, to which standard *protocols* can be applied for communication between layers. The NWS is also striving for openness in its information and dissemination systems. The WIST System inherits openness from these underlying systems and uses it to facilitate the deployment of decision support (including evaluation feedback) applications, viewed as the highest in the layer stack and interfacing directly to users. The functional goals of an open system architecture are:

- Competition in procurement
- Functional and technical system adaptability
- Transparency of the applications to the particular communications networks used
- Ease in fusing varieties of information in the decision support function

Open systems can break down information barriers within operating organizations, between organizations, and with travelers. This raises the issue of what information should be shared, such as over the Internet. Openness does not prevent restrictions, or fees for access. It only means that authorized users do not have to worry about special equipment and connections for their variety of communications needs.

The functional goals can be achieved to varying degrees by three concepts of openness, from weak to strong:

1. An open system meeting only the “competition” criterion can be defined as a published specification able to be licensed to multiple vendors.

2. An open system with a “standard” interface protocol between one or more layers allows changes on either side of the layer (different processes or technologies) as long as the way the layers communicate stays the same. This partly meets the adaptability and transparency goals and can meet the fusion goal at the application layer interface. The standard can be (loosely) a published specification that is dominant in practice, or strictly a published specification adopted and prescribed by a recognized standards organization.

3. A strongly open system is completely layered, so that the end-to-end connectivity from application to application is modular, and with standard protocols between all layers.

Formally, an open system connecting a database to a user must be specified as an application-to-application connectivity through two stacks of protocol layers. The source side extends down from the database to a physical communications layer (e.g., a wire, cable or radio channel). The physical communications layer connects to the stack on the user side, up to the display application. Intermediate layers handle the various translations of physical signals into properly routed and meaningful information to the user. A WIST System information thread will use all layers, but the development focus of this paper is on decision support in the applications layer of the system user. Coordination with the NWS involves, for the most part, their application layer of data sources. Other layers, including applications, used by the WIST System are mostly part of ITS or communications utilities. For instance, information from the NWS to a traffic management decision maker could come via the Internet (communication utility), and be effected via a roadside VMS (properly an ITS application).

Functionally, the WIST System requires that any user anywhere can access an arbitrary mix of databases. The simplified scheme of applications on “infrastructure” layers is used to emphasize that from the user end, it appears that the system is tapping a common pool of information and all the intermediate layers are transparent. An example of this system at work would be itinerary planning by travelers. The traveler needs route condition and services information from a variety of spatial points, and referring to a number of time horizons. The source applications will be physically and institutionally separate, but the appropriate user application could access all these sources and display them along one itinerary. Flight planning is now able to access information in this way for the airspace. Surface transportation and ITS have yet to establish an interstate, multi-source, communication capability so that similar surface-travel applications can be marketed.

Any open system contrasts with, for example, a proprietary RWIS that requires buying an end-to-end package from data source to display, with no way to mix in other information for the user. A multiplicity of such “stovepiped” systems is what leads to “swivel chair integration” by the user to meet all information needs, and not well. This is why a current RWIS user usually has at least three separate information feeds and physically separated displays (typically a remote sensor display, a tailored weather forecast display, and one or more NWS or other public sources).

The ITS has made a step toward standard layering in the WIST System by adoption of the National Transportation Communications for ITS Protocol (NTCIP) Environmental Sensor Station (ESS) standards. This will apply to interfaces of fixed and mobile sensors to a “center” (i.e., an ISP, weather office or transportation office, but generally not to travelers). The ESS standard opens one of the proprietary parts of RWIS and allows other applications to be integrated. An ESS is properly part of the ITS infrastructure.

The strongest definition of an open system is an ideal rarely achieved. The Internet is a published standard incorporating upper layers of the protocol stack but is not completely decomposable. It does meet most functional goals, of allowing competitive access of applications to a variety of databases (actually other applications), with transparency to a number of communications media (telephone, cable, wireless at various data rates), and adaptability to a number of platform (computer/operating system) technologies. However, some applications do not need this openness and it may be economical to provide only simple and uniform displays. These can be “canned” and distributed widely, even bundled with their own communications links (e.g., roadside kiosks).

The strong open system requirements originally were intended for computer-to-computer communication, but the variety of end-user types and applications results in bundling of communications and other layers. The strongest differences are between fixed-site, computer-based applications needing high data rates (e.g., a weather forecast office) and mobile, voice communication applications that may afford only low data rates (e.g., a traveler with cell phone). A variety of communications media, incorporating various sets of protocol layers, can serve specific kinds of applications and users. It is important for the WIST System to exploit these to expand the dissemination of weather and other transportation information:

- Telephone (twisted pair) service for low data rate Teletype, facsimile and home Internet.
- Cable for high data rate services, including Internet, local area networks (LANs), wide area networks (WANs), etc.
- Radio and TV broadcast media for general weather warnings (including NOAA weather radio) and traffic information.
- Satellite broadcast for some vendor services and low data rate NOAA Weather Wire Service. NOAAPORT is an NWS satellite broadcast medium for high data rate NWS dissemination and may become the preferred medium for the NOAA Family of Services products.
- Highway Advisory Radio (HAR) for local broadcast of highway information. Compare to variable message signs (VMS) that are preferable for short advisories that all traffic should be aware of.
- Radio Broadcast Data System (RBDS), Subcarrier Traffic Information Channel (STIC) and other systems that use FM or AM broadcast stations to carry low data rate messages over wide areas to car-radio alphanumeric displays or to trigger voiceover weather and traffic messages.
- Dedicated Short Range Communication (DSRC) transponders to function like HAR for data or for bursts of two-way roadside transactions.
- Cellular phone for voice and low-rate wireless data. The voice transactions can include recorded and route-specific traveler information accessed through dialpad codes. The data can serve pagers and mobile data terminals (MDTs), or send update information to vehicle navigation systems. Preferable for data are various digital wireless services such as cellular digital packet data (CDPD).

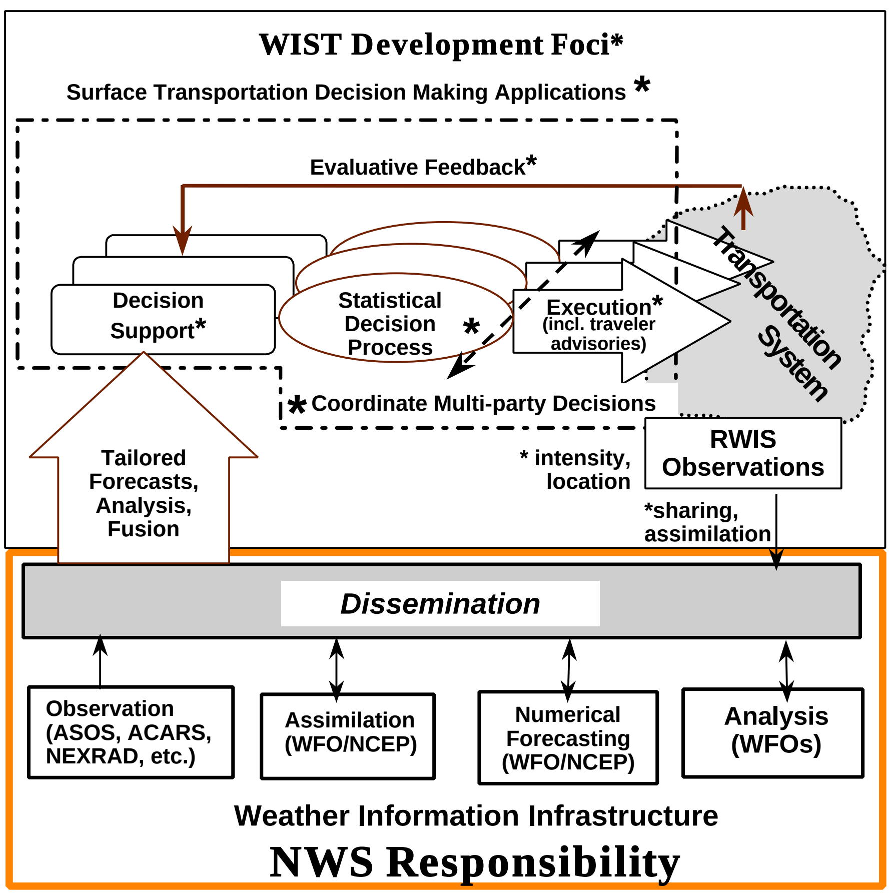
The Internet is the most generic data medium (actually, a subset of protocol layers). It is often deficient in data rates and reliability, but these are set by the servers and communications used. With appropriate communications network management and investment in adequate server capacity, the Internet can replace proprietary channels and reliably connect many WIST System applications.

Among mobile applications, commercial vehicles may afford satellite communications links and MDTs linked to dispatching offices. The private traveler probably will continue to rely on a variety of bundled services through broadcast radio (news reports, HAR, RBDS, etc.), VMS, DSRC, and cell phones. Fixed kiosks with travel and services information will continue to be important. Use of two-way mobile communication links (e.g., cell phone) for multiple services like advisories, navigation, sensor reporting and emergency request (“Mayday”) will be important to affordability and user acceptance. The full vision of WIST decision support probably will be applied only in fixed locations for transportation system management, but better integration of data sources for pre-trip and en route travel planning, at home or in-vehicle is also a priority.

The Weather Information Infrastructure

The NWS system, viewed as an infrastructure below the ITS, is at least as complex as the ITS. It properly has to be shown as its own set of applications and other layers. However, the important point is to define some demarcation between what is under ITS control and what is under NWS control. The figure below marks with “*” the WIST System components of primary Weather Team focus.

Figure 7: The WIST System and the Weather Information Infrastructure



The arrow of inputs to decision support crosses the WIST/NWS boundary. This is where responsibilities may shift between the NWS and the transportation domain. As NWS products improve, they displace some specialized products formerly produced by vendors. Some NWS products are sufficient to be piped directly through the WIST thread. However there is a regulatory boundary that the NWS cannot tailor products for specific users beyond the NWS mandate for public weather information. The practical and legal meaning of this stricture will continue to evolve. The important point is that in most cases, WIST decision maker needs will have to be met through WIST System development, and not through the NWS. The NWS is always open to expressions of user needs, but pursuit of these needs should generally start with the assumption that NWS products are the best they can be within current technical and budgetary limits.

The four basic parts of NWS weather information processing are observation, assimilation, numerical forecasting, and analysis. In meteorological parlance, "analysis" is the process of transforming data into meaningful weather predictions. This was formerly a matter of human inference from observational data, but since the 1950's numerical modeling has played an increasing role. Meteorologists will make a distinction between weather forecasts, that result from analysis with human decision making, and "numerical guidance" from the computer models. Richer observational sources, such as doppler radar, now augment the point observations and provide near-horizon prediction by vector tracking of storm cells.

The NWS, air transportation, and maritime transportation make atmospheric observations. Air carriers automatically provide winds, temperature and humidity aloft through their Aeronautical Radio Inc. (ARINC) Communications Addressing and Reporting System (ACARS). Verbal pilot reports (PIREPS) provide turbulence, icing and other information of interest to aircraft. The NWS relies on the Automated Surface Observing System (ASOS) for surface observations. There are nearly 1000 ASOS sites in the U.S., and over half are operated by the FAA or the Air Force[24]. The NEXRAD doppler weather radars, and some atmospheric sounding radars, provide important atmospheric-volume information on winds and precipitation. These are supplanting traditional optically- or radar-tracked balloon soundings (radiosonde or rawinsonde). Stationary and polar orbiting satellites track large storms and can give some atmospheric and surface attributes. This wealth of observations has supported finer resolutions and more rapid updates in the numerical modeling and analysis.

Observations are assimilated. They are cross-checked with each other and with numerically predicted fields for error control, and they are put into appropriate grids and formats for numerical modeling and dissemination. This process smoothes away some real, fine scale, observational data. Human analysis is another phase of error and consistency checking. Numerical models are initialized by the assimilated observations, but also add information, of solar inputs and the atmospheric hydrodynamics, to the observations. For this reason the effective resolution of numerically processed observations is about four times that of raw data grids (e.g., a 100 km sensor grid effectively becomes a 25 km grid at short forecast horizons). The raw observations do have the utility of immediateness and non-smoothing of their measurements. Depending on the kind of decision to be made, raw, assimilated or forecasted observations may be needed. Fusion of observations and forecasts, as of NEXRAD and small scale numerical forecasts for convective storm prediction, may be desirable.

There are a variety of numerical models supported by the NWS, or applied by vendors within NWS-produced boundary conditions. These will be discussed below relative to decision scales.

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[24] ASOS, compilation of reports from the AMS Meeting, January 1998.

The NWS operates central and regional facilities. The National Centers for Environmental Prediction (NCEP) provide global data assimilation and large scale numerical forecasting. This supports the decentralized analysis of the Weather Forecasting Offices (WFOs). The WFO functions are being reinforced by the added processing capability of the Advanced Weather Interactive Processing System (AWIPS). The AWIPS mainly gives decision support for human analysis. However, recent builds of AWIPS are providing the capability to do local data assimilation and fine-scaled numerical modeling through the Local Analysis and Prediction System (LAPS). This decentralization of the NWS numerical modeling can make use of local and specialized datasets such as RWIS. The Weather Team's demonstration project hopes to exploit these new products. The WFOs have been responsible for warning and other dissemination products via human analysis. The demand for direct data from the LAPS for external analysis prevents WFO control of the quality of that vast amount of data, and may raise significant liability and quality control issues.

The vendor role will persist because few transportation agencies will choose to invest in staff meteorology, or systems developers. However, the surface transportation community could move toward the aviation weather approach. The close cooperation of the NWS and the Federal Aviation Administration (FAA) includes the Center Weather Service Unit (CWSU), an NWS-staffed weather forecasting operation in air route traffic control centers (ARTCCs). This model could apply to surface transportation as well. The issue is where and how specialized analysis occurs, especially if it requires human meteorological expertise and expensive decision support like AWIPS. The functions could occur in WFOs, in centers operated by vendors for multiple clients, at an intrastate traffic operation center, or at a larger interstate level. It implies transportation agency funding of meteorologists.

The technical process of the NWS accompanies a changing paradigm of service delivery by the NWS, consistent with the decision-focused view developed here. The Grand Forks, ND flood of 1997 illustrated a case of good weather forecasts, with long time lead, provoking inadequate response. In this case, the uncertainty in the flood levels was not used properly in preparedness decisions (i.e., only a 5 foot forecast error even at a 2 month horizon, but around a critical 49 foot flood level)[25]. As a result, an interactive triad is recognized of forecasting, communications, and decisions by the end users. These three elements are not just sequential. Therefore a close partnership is required between the NWS, the ITS and the WIST System to make the complete triad work.

Specialized Observations

The RWIS has emphasized specialized sensors for road pavement, and near-road surface observations. This alleviates a deficiency in the NWS weather information infrastructure, but also creates a transportation responsibility for part of the weather information infrastructure. The task remains to share the observations with the NWS forecasting process, and to assimilate all observations into a quality-controlled database.

NEXRAD observations provide near-surface wind, precipitation and convective storm information over large volumes. Satellite imagery performs some of the same service at coarser resolution. These observations may be of more direct interest to surface transportation than the sparse ASOS site observations. However, in terms of comparing what the NWS measures as

[25] Pielke, Roger a., "Evaluation of the Societal 'Goodness' of Forecasts", paper J1.1 in 16th Conference on Weather Analysis and Forecasting, AMS annual meeting, Phoenix, AZ, January 1998. The example was brought out in the presentation accompanying the paper.

surface attributes versus what surface transportation needs, the comparison is with ASOS in the table below:

Table 1: Comparison of Surface Observation Data

NWS Surface Observations (Based on ASOS capability[26])	Attributes of Surface Transportation Interest
Temperature (ambient air)	When phase change (freezing) is reached, and when excessively hot
Dew point temperature (relative humidity)	Of interest when dew point is below ambient and causes surface tractability problems
Pressure	Generally not of interest
Wind direction and speed	When high gusts cause facility damage, vehicle instability, snow drift or debris problems. Wind generally of interest for air pollution or Hazmat plume transport.
Precipitation type and amount (intensity and accumulation)	Of interest.
Cloud height and amount	Of interest regarding insolation for air pollution and surface temperature prediction.
Visibility range	Of interest when severely limited.
Local visibility limitations (fog etc.)	Probably not indicative far from sensor (i.e., on roads).
	Pavement/track surface and subsurface temperature
	Pavement surface salt concentration
	Pavement/track tractability
	Pavement/track ice/snow/water coverage
	Air pollutant concentrations.

Surface transportation observations can be made by various means. RWIS sensors typically include the above-ground measurements of temperature, wind and precipitation, that should be comparable to ASOS measurements. The RWIS sensors also provide pavement temperature, ice/snow/water coverage and salt concentration needed by road managers. Areas with air quality attainment problems deploy a limited number of monitoring stations that measure meteorological attributes and pollutant concentrations. Visibility monitors are installed where particular problems exist. Traffic surveillance cameras can measure visibility and pavement ice/snow/water coverage. Mobile probes can provide the same data as the fixed RWIS sensors, as well as direct measurements of tractability (pavement LOS).

The combining of specialized and NWS observations into one assimilated database is desirable in principle, and problematic in practice. The specialized observations can benefit from cross-checking for error control and automatic detection of calibration and repair needs. In practice, any sensors on or near pavements and structures tend to be highly biased from other surface

[26] ASOS, op. cit.

sensors and the actual amount of cross-validation or usefulness of measurements is questionable. The detailed variation of pavement observations makes it unlikely that enough comparable observations will be available from fixed sites for cross-checking within the group, but this procedure may apply to numerous and more error-prone mobile sensors.

Surface transportation observations must account for much finer variability than do the atmospheric near-surface observations. Being on structure, at grade, in cut or on fill makes a big difference in flooding, snow drift, winds and freezing. A strategy is to develop interpolative and predictive applications within the WIST System to make use of any sparse set of observations and apply them along route links. This puts an even higher premium on correctly calibrated and reliable sensors.

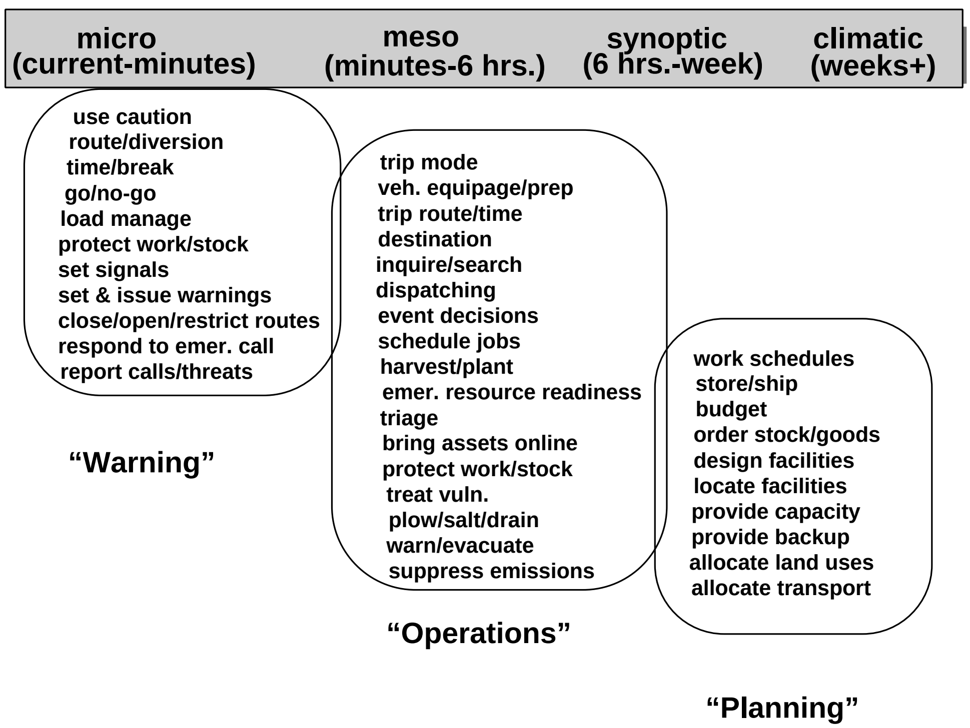
Operational Scenarios

The variety of decisions accommodated by the WIST System covers many scales and can be illustrated by some example scenarios. The scenarios are only sketches of operational concepts and detailed functional descriptions eventually will be necessary to generate WIST System requirements in the ITS architecture.

Decisions and Scales

Decision threads can be categorized by type of decision maker or type of output. The most important categorization is scale because this relates to weather information sources. Scale is in terms of the spatial area and time horizon. The figure below shows some kinds of decisions by scale:

Figure 8: Decision Scales



The decision scales are called warning, operations and planning. The table below shows more detail on decision types. Corresponding weather scales in terms of time horizon are micro-, meso-, synoptic- and climatic-scale. Different data collection and modeling processes are used at each scale, and always with an increase in uncertainty accompanying an increase in scale. Weather phenomena are physically scaled. Convective storms are short-lived and spatially local. Decisions about these severe storms depend on observation (e.g., NEXRAD storm tracks or lightning detectors) and meso-scaled predictions. Large frontal and air mass systems are more persistent and extensive, and decisions about them (e.g., keep the crews on alert for a snowfall) can usefully go to synoptic scales. Even more persistent are global climate cycles and trends, and the climatological scale can be useful for some decisions.

Table 2: Transportation Decision Making

	Scale of Information/Decision		
Decision Maker	**Micro (Warning)**	**Meso to Synoptic (Operational)**	**Synoptic to Climatic (Planning)**
Traveler (general)		trip mode, routing, departure time, cancellation	itinerary, baggage
Traveler Awaiter		meet, make inquiry, request search, perform search	request visit
Vehicle Operator (general)	caution (speed and following distance), steer, brake, turn, operate equipment, go/no-go	Trip destination, route, breaks, times, fueling, cancellation Vehicle equipage/treatment (e.g., chains, anti-freeze, oil)	
	Varieties of vehicle operators: Commuter/Local, Long Distance Recreation Tripmaker, Police, Ambulance, Snowplow Operator, Transit Bus Driver (fixed route), Bus/Taxi Driver (demand route), Train Engineer, Local delivery Truck Driver, Long Haul Truck Driver		
Fleet Operator (general)	update locations, update route, update schedules	dispatch (time, route, driver, transfers), fleet equipage/treatment, fleet loads, store/forward, fleet relocation	Fleet selection, equipage, periodic maintenance. Locate facilities, provide backup. Order consumable stocks.
	Varieties of fleet operators: Highway Maintenance, Transit, Taxi, Railroad, Commercial Truck (private, contract, common carrier), Public Safety, Repair, Construction, Harvesting, Military		
Event Operator	cancel, evacuate, delay	proceed/cancel, shift time, mitigate weather impacts, advise routing	shift date, relocate, provide capacity (e.g. parking), mitigate weather impacts
Highway and Rail Operators	signal settings, set speeds, post warnings, close/open route/lanes/track	close/open route, restrict route (incl. speed, direction, HOV and tolling)	
Highway and Rail Maintainers	plow, salt, drain (operate pumps, clear drains), clear obstruction, hazard warning	Inspect/repair damage, schedule work, crew alert, place crew/fleet and request aid, treat vulnerabilities	seasonal work scheduling, replenish consumables stock, hire crews, budget
Highway and Rail Constructor	protect work, protect onsite stock, shelter crews	schedule jobs, protect work	schedule projects, order equipment and supplies, hire crews
Highway and Rail Designer			Specify grades, curves, materials, equipment. Locate facilities.
Regional Planner		suppress emissions (pollution alerts), demand management, mode and route diversion	allocate/regulate land uses, allocate transportation capacity, achieve air quality conformity, attain air quality

Other decision makers with some relation to surface transportation are manufacturers of transportation equipment, producers of goods that are shipped, utility suppliers, disaster managers, service operators, travel agents, and developers. The ITS architecture defines information service providers (ISPs). ISPs can be conduits for weather and traffic information by disseminating broadcast reports or subscription services. They can straddle the fine line between providing information in decision support, and providing directives (decision making).

Air and water transportation decision makers will have intermodal interests with surface transportation. Inland waterways can have a vital relation with surface transportation, through weather, because of Corps of Engineers and other canal authority flood control functions.

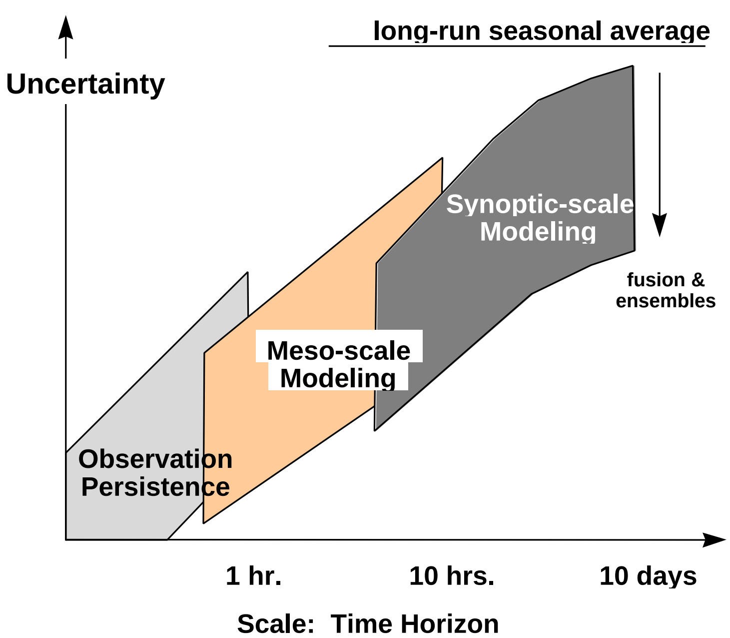
Among the decision regimes, warning is associated with conditions that need rapid responses (short horizon), typically applies to individuals (spatially local) and is often safety-critical. Operations are associated with agencies and management of aggregates of activity, so that horizon and area are in a middle range. Planning, although it is really just another name for decision making, is used for the larger scale and where the decision process tends to be done by many participants using an explicit sequence of data collection, analysis, programming and execution steps.

Some decisions are at multiple scales and need to fuse different predictions. A good example is travel planning over a long itinerary. Each point on the itinerary is a potential decision point for stopping, going, or choosing an alternate route. The appropriate fusion of information has to be specific to where the traveler will be at a given time, and that in turn depends on prior decisions that may depend on weather.

Weather Forecasting Methods

Actions are always based on past information, meaning that decisions always use and make predictions[27]. The figure below shows the ranges of weather forecast uncertainty with scale indicated as time horizon.

Figure 9: Weather Information, Uncertainty and Scale



Meteorology has many measures of the uncertainty of forecasts, but conceptually a standard deviation between forecasts and later observations of reality can be used. Uncertainty grows

[27] There is no formal distinction between "prediction" and "forecast". The term "forecast" typically will be used for weather and other information resources to a decision, while the decision itself makes "predictions" about outputs and outcomes in order to choose a best action.

with scale (both in time and space) because of errors in the data, deficiencies in the models, and limits on communications capacity and computer power. The absolute uncertainty at any scale is a function of investments to shift these limits. However, it is inherent that uncertainty grows with scale but is asymptotic to a cyclical (diurnal or seasonal) average value. For instance, a forecast of temperature or precipitation made in January for next July will have near-minimum error if it just uses the average over the last several years for late June or early July. What is important about the error growth with scale is that the effectiveness of investing in observations and high-resolution models diminishes with scale. Investment in observations can make knowing the present as certain as desired, but it cannot be as effective in making the future known. As the horizon increases, the use of observations shifts from direct use at the point of observation, to initializing numerical models over a set of points, to establishing a climatological time series that captures point biases (e.g., being in the shade).

The figure indicates that having model ensembles reduces uncertainty to lower bounds. Increasing computer power allows running multiple models within a given cycle time to create the ensembles. Other than that, observation quality and quantity (accuracy, precision, density and frequency) are the investment objectives. Observations are the basis for building better numerical forecast models and for re-initializing the models every time they are run.

The forecast modeling technique changes with horizon. At the smallest scales, observations are used directly as forecasts, the persistence model that locally and in the near future the weather will be just what is measured now based on the inertia in atmospheric dynamics. Over longer time horizons the changes are driven by external energy (the solar forcing input) and the internal atmospheric dynamics over larger areas. Over longer horizons, local weather is affected by atmospheric conditions farther away. This leads to the practice of nesting models. A high-resolution meso-scale model is initialized from a local observation grid, but uses boundary conditions from a larger scaled (e.g., synoptic) model. Intuitively, a fine observation grid far away is not going to help local forecasts very much, because correlation diminishes over space. The corollary is that the effectiveness of high-resolution observation grids decreases with time horizon. The payoff to intensive observation is most at the persistence and near-meso scales.

Use of climatological time series is another form of persistence forecasting. Since several months are a short time compared to a data series of many years, it is assumed that a seasonal average from the past applies in the future. The time series can also capture longer cyclic and trend effects, as is the case with El Nino or “global warming”[28]. Models of these effects must be based on long and global time series of data, even to millenia. Planning, as for when to do construction tasks or when to put the plows and spreaders on maintenance fleets, regularly uses the seasonal average, and could use better climatological forecasts.

It is important to understand that forecast error growth is equivalent to a smearing of spatial resolution. The uncertainty bounds over time at one point begin to include the forecasted variations at nearby grid points, and arbitrarily fine resolution cannot be achieved at long horizons. The NWS chooses, with respect to economy and inherent model and observation resolution, to disseminate certain time horizons and grid resolutions of data. NCEP produces national-scale Eta model results to 32 km resolution for multi-hour horizons. The Local Analysis and Prediction System (LAPS) to be deployed in WFOs at state-scale will produce resolutions of 10 km, but after a few hours the effective resolution is that of the large scaled model in which LAPS is nested. In general, little is going to be gained by interpolating the grid points of a model

[28] There is an issue as to whether these effects are really cyclical, trends or random variations. Over any short horizon they will look like trends imposed on a “normal” seasonal cycle.

to a point of local interest (like your vehicle location). More can be gained by using multiple points as a statistical ensemble for a central point. Vendor services can add local expertise to NWS forecasts, but unless they have access to an observation grid finer than that available to the NWS, their benefit cannot be based on better resolution than that provided by the NWS.

Atmospheric forecasts will be almost entirely independent of a specific RWIS-type observation, but can benefit at local scale from a field of additional surface sensors. Pavement condition forecasts are a function of the pavement surface and subsurface observations and the expected atmospheric condition (e.g., whether snow falls on a warm or cold pavement). At small scale, RWIS-type observations can fully characterize pavement conditions and be applied to forecasting by persistence. This includes pavement models that spatially forecast for points away from the sensors. For longer horizons atmospheric effects play a larger role, by changing insolation, adding precipitation, etc. The net result is that at increasing time horizon, more specialized observations have diminishing effect on total uncertainty. Therefore, transportation investment decisions regarding specialized sensors most affect small scale forecasting (near the sensors, and out to roughly an hour horizon). Beyond that, predictive uncertainty can be reduced only by general improvement in NWS forecasts.

The scale separations between types of forecast models are not sharp. At horizons of roughly ½ to 2 hours, there are interesting possibilities for fusing direct observations in a local area with meso-scale numerical results. In the case of convective storms, direct NEXRAD observations are the best predictors at horizons under an hour, by tracking storm cell vectors. Beyond that it is useful to employ the dynamics in the numerical models, that go beyond linear vector extrapolations.

The key conclusion is that while the transportation community always needs "more accurate" forecasts, the ability to achieve these is limited, and scale-dependent. Resolution and horizon are not arbitrarily specifiable: high resolution will exist only at short horizons. The transportation community has the opportunity to improve short horizon pavement condition forecasts by sensor investment. At longer horizons, they will have little effect on NWS quality. This prioritizes a focus on better use of the existing forecasts through better decision support and fusion of the variety of sources. Not every forecast needs a numerical weather model, but all forecasts carry an uncertainty that needs to be accommodated by risk decision making.

Example Decision Scenarios

The examples below are narratives that illustrate decisions by a variety of decision makers at a variety of scales. In almost all cases, weather and other information is obtained through channels that are available or planned as part of the ITS. The examples pose the question of how the WIST System should complement the ITS and support decisions in ways that lead to better outcomes.

Example 1: A Morning Commuter

The commuter wakes up to a radio news channel. The news says that heavy overnight rains have flooded low-lying areas, and slick roads already have caused some accidents. The commuter checks the Internet, where the regional Traffic Management Center (TMC) maintains a website showing traffic flows on major routes and incident warnings. An information service provider (ISP) also provides an email message every day tailored to the commuter's route, and supported by an advertising message on the note. The TMC website shows some high water over a primary route, thanks to an RWIS sensor site that includes a water level meter at a critical culvert. This is not on the commuter's normal route, so the commuter decides to go the normal way. On the way there is an old-fashioned water level stick that is in a puddle where a culvert on a local road is spilling over—but it's only a few inches and just requires driving slowly through it. On the way in, the commuter re-tunes to the news station and presses the "MSG" (message) button on the radio. Every 10 minutes, a voice message preempts the normal broadcasting to give an update on significant road conditions. News of more accidents reinforces variable message signs (VMS) along the way that warn of skidding on the wet pavement, so that everyone is going slower. This means a little more congestion too, that has been significantly alleviated by diverting some drivers to the transit line, through TMC prompting on their website and over broadcast radio.

Example 2: A Long Distance Vacation Traveler

The Joneses are driving on a winter vacation from Cleveland to Lake Tahoe, and plan to stop for entertainment in Reno and an overnight at relatives in Boulder. Although they listen to the TV weather news the night before leaving, and glance at the weather map in the morning newspaper, there is nothing specific for conditions near the Rockies in two days, or for the Donner Pass to Tahoe on the fourth day of their trip. They would use the Internet for a detailed set of forecasts, out to 72 hours, on a free website, but they have reservations and see nothing to be very concerned about before leaving. In their car, the Joneses have a navigation system with a national route database for the major roads and a Global Positioning System (GPS) receiver to track their progress. The navigational system has an interface with the car radio to receive subcarrier messages on road conditions, and can re-route accordingly. Unfortunately, only some FM stations carry this service. The Joneses also bring their cell phone that can access voice messages. They get over the Rockies all right. When leaving Reno, there is no snow in the valley, but they did see a sign about a cell phone travel information number when coming into town on the Interstate. Mr. Jones dials the number and hears a voice asking to "Press 3 for travel west over I-80". Jones hears that the pass is open but that all cars going over the pass are required to have chains because of an overnight snow on the mountains. Mr. Jones mutters "Lucky I saw that sign for the cell number", and asks the motel clerk where he can buy a set of chains.

Example 3: A Common Carrier Trucker

Bob, who drives for Capon Trucking, has a reefer full of beef to haul from Wichita to San Francisco. He is based in Kansas City, but the dispatcher is always in contact via satellite link to Bob's mobile data terminal. That is how he got the current assignment, and he can haul back a load of scallops, if he gets to San Francisco in 60 hours. Bob figures he can do that legally if there are no delays. The dispatcher has already calculated the minimum-time route, pretty much due west over the Rockies and the Sierras. But that all depends on conditions, especially in the high passes. The other route to the south would have fewer weather problems, but the route choice up through California on I-5 depends a lot on traffic and when Bob arrives at bottleneck cities. It is an El Nino year, and there is a real threat of heavy rains that can cause mudslides on I-5, or heavy fogs that have resulted in chain-collisions and highway closures. It's a close choice, and Bob wants some better weather and traffic condition insight from the dispatcher before making a choice of heading west or heading south. The worst case would be to go west into the Great Basin and then have to divert south. Bob messages the dispatcher for the weather forecast along both routes. The dispatcher has new routing software that can give risk evaluations of different routes and uses probabilistic forecast information from the NWS. The system reports back that for the direct westerly route the expected time is 49 hours, and 55 hours for the southern route. However, there is a 10% chance that the westerly route will exceed 60 hours, and only a 5% chance that the southerly route will. It's still a tough choice, but bolstered by just a 10% chance of missing his return load, versus more time and fuel the other way, Bob proceeds west.

Example 4: A Regional Traffic Management Center Manager

Jane runs one of the traffic management centers (TMCs) along the Northeast Corridor. They monitor the Interstate routes in their jurisdiction, and there are only two parallel routes that handle the through traffic. There can be a big difference in weather conditions on the two routes. There is more snow inland, but the occasional hurricane is more likely to flood the coastal route, and the worst fogs are coastal. If either route is shut down, because of weather, serious accident or the still-remembered case of a bridge collapse, there are at least a dozen TMCs, over several states that have to be notified. For local actions, TMC managers consult various probe and sensor monitors and activate control VMS displays. This requires a lot of attention from the managers, and there is still debate about whether the monitors should automatically trigger the VMS displays. The worst cases, when strategic coordination between TMCs is required, is also when the managers are most preoccupied with tactical control. There is still debate about what strategic control should be allocated to a super-TMC, and whether they need all the RWIS and traffic sensor information from the local TMCs. In any case, strategic control, across all the TMCs, requires a 6 hour warning on severe storm tracks and heavy precipitation. But Jane realistically knows that the longer the lead, the less accurate the information, so they have to keep fine-tuning. This takes a lot of communication between the TMCs and with the weather forecast offices.

Example 5: An Area Road Maintenance Manager

The manager knows that the public and politicians expect clear roads, regardless of the weather or failure to predict it. For this reason, the manager avoids risk, by surrounding himself with a lot of weather services and road sensors. Since weather information is relatively cheap compared to all the road maintenance resources, the manager really has too many screens to look at, and wishes that there was just one system that didn't tell the weather, but rather exactly where and when to put crews to deal with flooding, freezing or snow. The manager thinks the same of weather forecasting as the road users think of road maintenance: Good forecasts are expected, but people never forget the big storm that was missed, or the big storm forecast that fizzled. How can someone who is not a meteorologist really make sense of all the information, and assess its reliability? Moderate snowfalls or pavement freezing are the most common case and determine most of the budget. In these cases, precise control on where the crews plow and how much they spread is needed to reduce costs, and this is best done with a lot of sensor information, including on the vehicles themselves, tied to smart dispatching. Longer range forecasting is needed to plan for crew overtime, or to get aid from a neighboring district. There is at least a 6-hour lead needed for crew scheduling in these cases, and preferably up to 12 hours to call for outside aid. The manager knows that forecast precision at those leads is tough, and wants some help, including professional standards on error thresholds, to translate weather forecast probabilities into expensive decisions.

Example 6: A Transit Service Dispatcher

Dispatcher Smith works in a large urban transit authority that runs rail transit, fixed route buses and handicapped passenger services. Smith works with the demand service "Dial-a-Ride", taking handicapped rider requests and using the computer to assign a vehicle and time to the request. Dispatching is more tactical than the scheduling function, that does the periodic runcutting (crew and vehicle shift assignments). On the fixed routes, dispatching has to deal with maintaining headways or altering routes due to weather. For demand service, dispatching is continually adjusting vehicle itineraries according to demand and travel conditions. The authority has a policy of getting ride requests 12 hours in advance to pre-plan the routes and give the drivers predeparture itineraries, but also they try to accommodate shifts in users' schedules at shorter leads. The objective is to maintain productivity (rides served per vehicle hour) by efficient rider-vehicle assignment with minimum vehicle hours, but still to have enough slack in the schedules to be sure no riders are missed or delayed. That is a tough balance, and it depends on the best forecasts of what is going to happen 12 hours ahead, and down to shorter lead times. That depends on weather conditions, that will determine vehicle speed, and the increased time for boarding elderly and handicapped people when weather is bad or there is snow cover and drifts. On top of that, bad weather generally makes the riders' schedules more variable. What the computerized dispatching system really needs is a set of forecasts at lead times from 1 to 12 hours covering the metropolitan region, and that can be matched to any vehicle itinerary to give route specific travel times, and loading delay factors. That might squeeze another 5% of efficiency out of the system, which over time is big money for the transit authority, and it means better customer satisfaction with better time reliability.

Example 7: A Regional Transportation Planner

Susan runs the regional network models for a large metropolitan planning organization (MPO). They do analyses of transportation performance for the region's long range plan, and analyze environmental impacts, especially of emissions and air quality for the State Implementation Plan. It used to be that Susan's models were not much concerned with weather: Traffic level of service (LOS) in the model was based on some "average" condition. The emissions model used some climatic constants for temperature, sunlight and air stability, agreed to with the Environmental Protection Agency (EPA). But now things are getting more complicated. As the region approaches air quality attainment, all the policy makers want to avoid just a few more hours per year when air quality standards are violated. This makes the difference in meeting EPA standards. The MPO has become more involved in forecasting, a day or two ahead, of when there are likely to be air-quality violations based on weather and travel activity, in order to invoke episodic control strategies. For the ozone problem, geographical specificity is not so important, but if the whole airshed had reliable forecasts on which way the pollutants were drifting, effective inter-regional action could be taken to reduce exceedences. For air quality and traffic management strategies, the MPO is also being asked to analyze ITS solutions, especially for adaptive arterial signals, freeway management, and traveler information. ITS effects are in response to changing conditions, rather than to annual "average" conditions. The MPO has to model the variability in traffic flow and weather over the highway network. Susan needs to understand how each weather condition affects the LOS of highways and signalized intersections. So recently, Susan has become more interested in historical weather information and forecasting at scales from the multi-day and regional, down to route-specific and hourly.

Needs

The Weather Team's two-day Workshop, held in June of 1997, gathered transportation and meteorological experts and practitioners. The workshop had preliminary presentations of this White Paper, presentations on NWS products and plans, and briefings on transportation-weather projects from around the U.S. The workshop produced versions of a vision statement, and a set of needs from working groups. Those needs are tabulated here as a basis for developing WIST program and system requirements.

The list of needs falls into two broad categories: those concerning "the system" itself, and those concerning programmatic coordination. The system needs were further grouped into three subcategories. The first subcategory addresses components of the decision thread, and is heavy on the weather information resource compared to downstream components. Then comes system integration, in terms of sharing resources, creating an infrastructure and an architectural/standards framework for open systems. Third are needs for general system attributes that will support and enhance the system. The programmatic category concerns support for the system by public and private agencies, and coordination between those agencies. The table below gives these grouped needs.

Table 3: Weather Information for Surface Transportation--Needs
1. Decision Support and Coordination System
1.1 System Components (Decision Process Thread)
Improved observations —more fixed sites —mobile probes —communications to NWS —siting standards —quality, precision
Observation accessibility —sharing of local observations —assimilation and quality control of consolidated observations
Improved forecast quality —surface/subsurface —above surface —largescale (initializations, boundary conditions) —specialized, localized
Improved analysis (surface transportation attributes)
Sufficient decision support —selective access to all relevant databases —appropriate fusion of databases —tailored to decision —tailored to human factors —better use of decision science (uncertainty)
Decision support effectiveness —dissemination of information to users —response effectiveness —resource control
Evaluative feedback (Best Mgt. Practices)

1.2 System Integration	
	Integration of systems: —wide areas —inter-jurisdiction —inter agency (inter-modal) —multiple functions (maintenance, management, traveler information)
	ITS architecture conformity
	Better use of existing resources (communications, probes, etc.)
	Appropriate standards for open system —NTCIP/ESS —other NTCIP —other standards
	Culture change: organizational, informational
1.3 System Support and Enhancement	
	Operational Concept /Best Management Practices
	ITS architecture requirements
	Operational assessment with payoffs (what customer wants/needs/will use)
	Reliable, maintainable, available equip.
	Deployment of existing technology
	Culture Change: —General knowledge base —Reduced institutional obstacles to change, to informed decisions, to effective decisions
	Training, trained staff (resources and education)
2. Program Support and Coordination	
	NWS/Weather Forecast Office understanding of surface transportation needs
	Public-private role allocation —Responsibility —Opportunity
	Point of contact for localities to federal agencies, especially NOAA, DOD
	Support the NWS (adequate funding, staffing)
	Federal deployment support funding and procedures
	Point of contact in USDOT to OFCM, and to weather-related standards
	Private sector support funding: Partnerships

Operational Concepts

The next step in needs development is the definition of operational concepts. These will be formalizations of the operational scenarios in the last section, for all the kinds of decisions to be served by the WIST System. Operational concepts are process scenarios and support requirements for achieving specified output goals. These will also be necessary for the further functional requirements definition discussed in the next section. The operational concepts will require detailed analysis of what decision makers do now, and then prescriptions of how best to operate with expected WIST System and other ITS improvements. These prescriptions are the best management practices (BMPs) to be adopted by professional organizations. The detailed operational concepts will also be the basis for quantifying many of the system requirements.

Needs Analysis

The intermediate step between needs and an action program is an analysis of issues requiring action[29].

The National ITS Architecture Process

The National ITS Architecture presents a structural concept of the ITS, and prescribes a systems engineering process to transform user needs into system requirements. Needs are mapped into a controlled set of ITS User Services. The User Services can be analyzed into functions that are carried out by technical and institutional means. The technical components are grouped with their functions into coherent Market Packages—the units that will tend to be developed and sold together. Open systems integration within and across the Market Packages is assured by standards, whose development is identified by the architecture. The operating institutions, whether agencies or individuals, will combine Market Packages into Service Packages, the appropriate units of deployment.

There is no "weather" User Service. It is not intended to make weather into a separate User Service. Weather information and decision making must be brought *into* an integrated ITS, not "added on" as another subsystem. The decision thread and WIST System structure is appropriate for mapping back into the several User Services that need weather information, as shown in the table below[30]:

Table 4: ITS Categories Related to Weather Information

User Services Bundles	User Services	Weather Information Needs
Travel and Transportation Management	• En-Route Driver Information • Route Guidance • Traveler Services Information • Traffic Control • Incident Management • Emissions Testing and Mitigation • Demand Management and Operations • Pre-trip Travel Information • Ride Matching and Reservation • Highway Rail Intersection	••Itinerary route weather and pavement surface condition ••Weather for destination services (e.g., skiing) ••Pavement LOS relative to traffic LOS ••Hazmat and pollutant runoff and plume conditions ••Ice, snow and water coverage of routes for treatment ••Other hazardous-travel weather conditions
Public Transportation Operations	• Public Transportation Management • En-Route Transit Information • Personalized Public Transit • Public Travel Security	••Climatic and storm vehicle-equipage ••Ice, snow and water coverage of routes for dispatching ••Ice, snow and water coverage of tracks for treatment ••Hazardous weather for vehicle operation or waiting passengers

[29] The background paper contains a detailed set of tabulations that derived actions from needs. This section only summarizes some of the issues uncovered.

[30] The User Services list may be found in the Executive Summary of the National Architecture for ITS, available on CD-ROM, USDOT. Also at the website www.itsa.org/public/archdocs/national.html

Electronic Payment	• Electronic Payment Services	••Severe weather that may affect toll system facilities
Commercial Vehicle Operations	• Commercial Vehicle Electronic Clearance • Automated Roadside Safety Inspection • On-board Safety Monitoring • Commercial Vehicle Administration Processes • Hazardous Materials Incident Response • Freight Mobility	••Itinerary route weather and pavement surface condition for dispatching ••Hazmat and pollutant runoff and plume conditions ••Severe weather that may affect toll automated roadside facilities
Emergency Management	• Emergency Notification and Personal Security • Emergency Vehicle Management	••Itinerary route weather and pavement surface condition for dispatching ••Hazmat and pollutant runoff and plume conditions ••Severe weather that may prompt search and rescue activity
Advanced Vehicle Control and Safety Systems	• Longitudinal Collision Avoidance • Lateral Collision Avoidance • Intersection Collision Avoidance • Vision Enhancement for Crash Avoidance • Safety Readiness • Pre-Crash Restraint Deployment • Automated Highway System	••Route weather and pavement surface condition for automated highway parameter setting ••Micro-weather and pavement sensing for vehicle control and probe transmission •• Severe weather that may affect automated systems

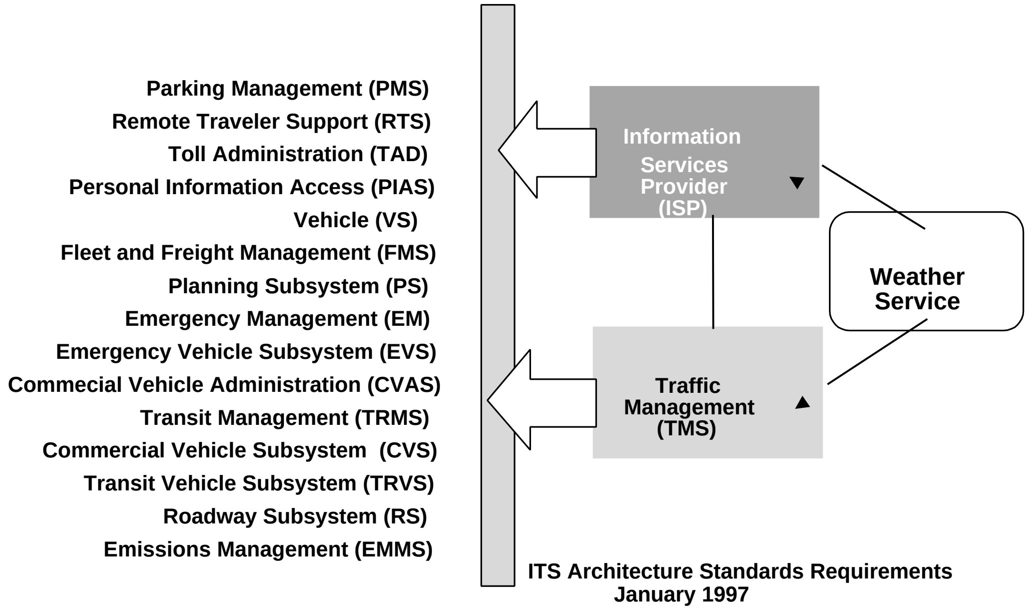
The National ITS Architecture Structure

The ITS structure[31] for weather information is very simple: An external entity called "Weather Service" sends current and predicted weather information to the Information Service Provider (ISP) and Traffic Management Subsystem (TMS) entities. From there, specific weather information flows are not shown, but they support many other ITS subsystems. The role of operational concepts and functional requirements will be to add more detail to this architecture.

The existing high level structure in the national architecture may not be the most useful for indicating the role of weather information and its channels. Highway or rail maintenance, which is emphasized here and in the RWIS, is a *not* subsystem in the national architecture. The "Planning Subsystem", that needs meso- to climatic-scale weather information does not have an explicit weather information flow, but probably would go to "Weather Service" as a source. The "Weather Service" may not be the only source of observations, and perhaps RWIS sensor information should come from "Roadway Subsystem". Similarly, vehicle probe data for weather might come from each vehicle subsystem. Evaluation information, that is emphasized in the WIST System thread, permeates almost all ITS functions, and needs to be shown as a separate layer.

[31] See especially Fig. 4-9, ITS Architecture, Standards Requirements, Joint Architecture Team, FHWA, USDOT, January 1997. See sources above.

Figure 10: Weather Information in The National ITS Architecture



The national architecture interconnection structure has been useful for specifying protocol standards, through which the architecture is implemented. At present, the one ITS standard directly applicable to weather information is the National Transportation Communications for ITS Protocol (NTCIP)/Environmental Sensor Station (ESS) standard. This was promulgated in 1998 and covers the roadside or probe sensor connectivity to TMS or ISP. NWS dissemination standards cover other connectivities. The operational concepts and functional requirements of the WIST System will be used to examine or create applicable standards.

WIST System Issues

The following are identified issues that motivate further research and development activities.

1. Specialized pavement observations
   - 1.1. Investment in observations. Transportation agencies have to invest in specialized observation systems. This will always be budget-limited and the issue is how to optimize sensor location and numbers relative to processing techniques and outcome improvement at various scales.
   - 1.2. Processing of observations. It is necessary to develop interpolation and prediction techniques to fill in and forecast information from sensors over the transportation grid. Full predictions require fusion of specialized observations and other data.
   - 1.3. Mobile sensing. When the communications and vehicle-locating infrastructure is provided by ITS, mobile sensing can be more comprehensive and efficient. This should be expanded among public fleets, and to private vehicles.
   - 1.4. Assimilation of observations. The specialized observations should be made available for assimilation into the NWS databases. Assimilation should also be used to detect when sensor repair or recalibration is required. The limitations of usefulness to the NWS or in problem detection among limited sensor sets should be explored.

2. Development Issues in the Infrastructure
    2.1. Enhanced meso-infrastructure. With advances in observations and computing, the NWS is producing high-resolution meso-scale analysis and forecasting. This will supplant some vendor products and should be used to boost the quality of all vendor products and applications.
    2.2. Quality control. More observations and meso-modeling produce a growing blizzard of data disseminated from the infrastructure, with the danger of putting too much data in the hands of users who are not qualified to use it competently. Quality control must be assured to limit liability.
    2.3. Meso-model ensembles. Ensemble forecasts are done now by the NWS at synoptic scale, but advances in processing speed make it feasible at the meso-scale.
    2.4. Doppler radar convective storm tracking. Road maintainers and others are very interested in severe storm tracks and precipitation. Accurate tracks are still beyond meso-scale modeling capabilities. However, at shorter horizons, doppler radar tracking can provide useful lead times and high spatial accuracy. Some challenges remain in differentiating precipitation types.
    2.5. Data archiving. The National Climatic Data Center of NOAA already archives weather observation and forecast data. This archiving is valuable for both planning-scale decisions and evaluation. The challenges to archiving and retrieval increase with the amount of data produced, and an issue arises of archiving responsibility for specialized surface transportation observations.

3. Issues at the Infrastructure/Applications Interface
    3.1. How good is good? An inability to quantify the affect on outcomes of improved weather forecast skill and resolution prevents the transportation community from making informed and practicable requests for better NWS or tailored weather information. It also prevents proper focus on other decision limitations.
    3.2. Specialized forecasting and analysis. The role of vendors should shift more into decision support as the demands of users become more refined and the infrastructure improves.
    3.3. Appropriate decision support. Users often are faced with a multiplicity of specialized products and “swivel chair integration”. Each decision support element has to be specific to the kind of decision and the environment in which it is made, but the decision support should converge into one, sufficient user channel.
    3.4. Statistical decision support. Distributional information appropriate to data fusion and risk decisions has to be supplied from the infrastructure.

4. Decision Thread Elements
    4.1. Data fusion for decision support. The fusion of model and direct observational data is especially an issue for tracking severe storms. Fusion of uncertain information must employ statistical decision techniques whose parameters will depend on the surface transportation decision (e.g., the penalty for false warning or missed event).
    4.2. Statistical decision making. There are inconsistencies and biases in decisions when information that has significant uncertainty is treated as certain. By using statistical information and risk decision procedures, additional gains in safety and efficiency are likely. This may be more efficient than trying to reduce the uncertainty further.
    4.3. Human vs. automated decisions. The challenge of risk decision making suggests that automation must encroach more on the decision making process itself, if not to supplant human decisions entirely. How human judgment should combine with automation must be better determined.

4.4. The human interface. Decision support has to be driven by better knowledge of the best formats for information in specific operational environments and for specific people.

4.5. Decision execution. This is a problem in complex organizations and where many decision makers, like travelers, must be coordinated. In safety-critical weather or pavement-condition advisories, as in speed control generally, the qualities of information that get appropriate responses must be better defined (another aspect of the human interface).

4.6. Evaluative feedback. In most cases there is inadequate observation of outputs, and outcomes. The necessary statistical analyses are not in place to infer causality between decisions and outcomes. Too much of what is done is just customary and taken on faith.

4.7. Standards from evaluation. Learning from evaluation should be propagated by operational standards. One form of standard follows the “best management practice” (BMP) format of other highway management, through the American Association of State Highway and Transportation Officials (AASHTO). Other standards come from other professional organizations. Because of the uncertainty and variety of decisions using weather information, the procedural standards will not be as clear-cut as, for instance, highway design.

5. Where to invest

5.1. Because of evaluation deficiencies, we really do not know where in the entire information infrastructure and decision thread the most benefit will be obtained for a given level of investment. However, there is strong indication that with large recent improvements in weather information, the focus should be centered on decision support. The issue is smarter use of existing information, whatever its uncertainty, before augmenting the amount of available information.

6. System integration

6.1. The Workshop elicited stories of duplicative investments and under-utilized resources that are partly due to jurisdictional boundaries, but sometimes just from lack of awareness. There is a very large institutional component to sharing and integration. Institutional cooperation has to be built by education on benefits and shared endeavors. The initial Weather Team project, through the Foretell consortium, and the existing Aurora pooled-fund research consortium, are excellent examples. These examples have to be extended within states, between states and internationally.

6.2. Hardware and software standards are needed to achieve open system goals. The WIST focus should be applied to the National ITS Architecture and to the NWS system to identify further standards issues.

Programmatic Issues

1. Institutional Boundary Issues

1.1. Limits to “tailoring”. The transportation sector can formulate better requests to the NWS for service, but the distinction must be made as to what is a “general public” improvement versus tailoring. Public sector transportation agencies are in a good position to request service from the NWS, but most decision support applications will be privately provided and raise issues of service to private sector interests.

1.2. Public-private ownership issues. Weather observations and transportation information are mostly publicly produced in the U.S. and eligible for inclusion in a public infrastructure. However, most applications will have some private sector participation. Issues arise over who owns and is liable for information, and who can assess a price for value-added services.

2. Federal roles
   2.1. Develop or deploy? The conceptual WIST System is beyond the state of the art and requires development work. However, NWS and vendor capabilities are increasing rapidly, and deployment planning and guidance should keep-up to move developmental products into the field expeditiously.
   2.2. Federal-aid funding for transportation can be used for most WIST System deployments. Any restrictions in law and regulation on this should be identified. It is likely that the next surface transportation legislation will support more development and deployment of ITS, and weather-related systems. In the case of state legislation and funding categorization, there should be an assessment of constraints to funding weather and other highway operations systems, as opposed to capital construction.
   2.3. Federal focal points. Transportation practitioners want to access federal weather expertise, especially as it resides in the DOD, NOAA and, within USDOT, the FAA. Better-defined points of contact, and coordination are needed. There is a tradeoff between brokering information requests to the best sources in the federal government, such as through the OFCM, or having contacts directly available to the field. Interests in weather information should also be more focused on the customer side. The customers are spread among state, regional and local transportation authorities, and private transportation operators, including trucking firms, motor bus operators and the rail corporations. The professional organizations of these customers can be used as a link to federal organizations.
   2.4. Federal coordination. Programmatic coordination as well as focusing field support requires better intra- and inter-departmental coordination. The Weather Team has a task to coordinate within the FHWA and across the surface administrations. The OFCM can play a role in coordinating with NOAA, DOD and the other USDOT administrations (FAA, MARAD and USCG).

Actions

The Weather Team will use responses to this White Paper, conference presentations and future workshops, to develop a program plan of specific actions. Some additional projects are in the budgeting and procurement process.

General Programmatic Actions of the Weather Team

1. The Weather Team will work through the ITS Joint Program Office to obtain high level USDOT recognition as the focal point of surface transportation weather program coordination among the surface modal agencies of USDOT, and with other federal agencies. Coordination will include joint planning for all agency programs that support research or operational tests for surface transportation weather information.

2. The Weather Team will, via the OFCM, develop formal cooperative agreements between the NWS and the USDOT.

3. The Weather Team will solicit participation from the USDOT surface transportation agencies (FHWA, FTA, FRA and NHTSA), the NWS, the DOD and other relevant agencies to draft a National Surface Transportation Weather Program. This Plan will contain the mission, goals and objectives of inter-agency activities to improve transportation outcomes by improvements in support, effectiveness and coordination of surface transportation decisions.

4. The Weather Team will draft a multi-year Program Plan of activities to fulfill the National Plan. The Program Plan will contain research, operational test and outreach project recommendations for funding under appropriate USDOT or other federal programs.

5. The Weather Team will maintain the Synthesis of weather-related projects and programs, and disseminate it through various media.

WIST System Developmental and Deployment Foci

1. The Weather Team will conduct the operational test initiated in FY 97, and use its results to refine project definitions in the Program Plan.

2. The Weather Team will promote development of a WIST System operational concept, and functional requirements for the National ITS Architecture. Requirements will ensure that open system standards promote common assimilation and use of all weather, road condition and environmental information for all related decisions.

3. The Weather Team will examine the state of the art, and state of the practice, and accordingly propose federally funded and evaluated research and demonstration projects to: 1) Better define operational concepts for the decision processes that produce transportation outcomes by use of weather information; 2) Develop techniques, hardware, software and communications to implement the WIST System concept; 3) Demonstrate appropriate

institutional arrangements, including public-private partnerships for WIST System development and deployment, and; 4) Test WIST System components integrated into the ITS.

4. The Weather Team will review federal-aid deployment programs to ensure eligibility and inclusion of the WIST System.

Other Actions

Not all actions relevant to WIST System development and deployment will be under the Weather Team, nor under direct federal sponsorship. Key roles are played by other federal agencies, especially NOAA, state DOTs, and consortiums that may be funded in part by federal aid. ITS applications are rapidly being developed by the private sector for public agency and private commercial use.

As part of the Delivery function, the Weather Team intends to track all relevant projects, and to seek special evaluation of projects with particular application to the WIST System. Information can be disseminated through existing channels of FHWA technical assistance and professional capacity building.

Standards activities through the ITS program are a vital coordinating activity. The Weather Team cannot participate directly in all relevant standards activities. The National ITS Architecture development will continue to create standards activities and require participation from qualified public sector and private staff. Other operational and design standards, especially Best Management Practices (BMPs) for operational decisions using weather information will be formulated by the appropriate professional and administrative associations. The Weather Team may identify deficiencies and encourage efforts by others in these activities. However, it is neither foreseeable nor desirable that the Weather Team will be central to, or participate in, all these activities.